



Monsoon research platforms over the ocean

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सार – जापान एजेंसी फॉर मरीन-अर्थ साइंस एंड टेक्नोलॉजी (JAMSTEC) एशियाई मानसून से संबंधित वायुमंडलीय एवं महासागरीय परिवर्तनशीलता के अध्ययन के लिए जलपोतों, मूरिंग्स तथा स्वचालित जलपृष्ठ वाहनों (autonomous surface vehicles –ASVs) जैसे विभिन्न साधनों का उपयोग करते हुए प्रेक्षणात्मक अनुसंधान कर रही है। विशेष रूप से, समुद्री महाद्वीप वर्ष (Years of the Maritime Continent YMC) नामक अंतरराष्ट्रीय प्रायोगिक अभियान कार्यक्रम या उष्णकटिबंधीय प्रशांत अवलोकन प्रणाली Tropical Pacific Observing System (TPOS) तथा वायु-समुद्र अंतःक्रिया अवलोकन रणनीति Observing Air-Sea Interactions Strategy (OASIS) नामक अंतरराष्ट्रीय बहु-राष्ट्रीय अवलोकन नेटवर्क के एकछत्रांतर्गत दक्षिण-पूर्व एशिया और प्रशांत द्वीपों के अनेक संस्थानों एवं विश्वविद्यालयों के सहयोग से JAMSTEC ने अपनी गतिविधियों को सुदृढ़ किया है। इस प्रकार के अंतरराष्ट्रीय सहयोग के अंतर्गत संबंधित स्थान पर किए जाने वाले प्रेक्षण के लिए स्थापित नेटवर्क और उपग्रह-आधारित प्रेक्षण व्यापक क्षेत्र तथा दीर्घकालिक अवधि को आच्छादित करते हैं, जबकि हमारे प्रेक्षण साधन मुख्यतः मध्यम-पैमाने (लगभग 100 किमी) पर स्थानिक तथा उच्च-रिज़ॉल्यूशन (जैसे प्रति घंटा या उससे अधिक आवृत्ति) वाले समय संबंधी आँकड़ों के संग्रह पर केंद्रित होते हैं, जिससे बहु-पैमाना अंतःक्रियाओं के दृष्टिकोण से अध्ययन किया जा सकता है। जब पोत-आधारित स्थिर प्रेक्षण किए जाते हैं, तब पोत के आसपास कई ASV तैनात करके प्रायः मध्यम-पैमाने का संजाल बनाया जाता है। इसके अतिरिक्त, गर्म जलक्षेत्र की वायुमंडलीय एवं महासागरीय परिस्थितियों को उच्च आँकड़ा-संग्रह अंतराल पर दर्ज करने के लिए दिसंबर 2016 से 13°N, 137°E पर फिलीपीन सागर मूरिंग PHSMO तैनात की गई है, जिससे दैनिक चक्रों का अध्ययन संभव होता है। इस लेख में इन प्रेक्षण मंचों के माध्यम से की जा रही मानसून संबंधी अनुसंधान गतिविधियों का संक्षिप्त परिचय दिया गया है। इसके अतिरिक्त, JAMSTEC के प्रमुख अनुसंधान पोत मिराई ने दिसंबर 2025 में अपना मिशन पूरा कर लिया है और वर्तमान में JAMSTEC द्वारा नया आर्कटिक अनुसंधान पोत मिराई II निर्मित किया जा रहा है; इसलिए मानसून अनुसंधान के लिए नए पोत के संभावित उपयोग की भी चर्चा की गई है। यद्यपि इसका मुख्य मिशन आर्कटिक अनुसंधान के लिए निर्धारित है, फिर भी इसकी संरचना और उपलब्ध प्रेक्षण प्रणालियाँ मानसून अनुसंधान सहित अन्य क्षेत्रों एवं अनुसंधान अभियानों के लिए भी उपयुक्त हैं।

ABSTRACT. Japan Agency for Marine-Earth Science and Technology (JAMSTEC) has been conducting observational research using several platforms such as ships, moorings, and autonomous surface vehicles (ASVs) to study atmospheric and oceanic variability related to the Asian monsoon. In particular, under the umbrellas of international field campaign program Years of the Maritime Continent (YMC) or international observation network Tropical Pacific Observing System (TPOS) as well as Observing Air-Sea Interactions Strategy (OASIS), we at JAMSTEC enhanced our activity through collaboration with many institutes and universities in Southeast Asia and Pacific islands. While in-situ observation network under such international collaboration and satellite-based observations cover wide area and long-term, our observation platforms themselves mainly focus on meso-scale (O(100 km)) in space and high resolution (e.g., hourly or finer) in time data collection, so that we can study from multi-scale interaction viewpoints. When we conduct a ship-based stationary observation, we often deploy several ASVs around the ship to form a meso-scale array. In addition, we have deployed the Philippine Sea mooring called PHSMO at 13°N, 137°E since December 2016 to capture warm pool atmospheric and oceanic conditions with high data sampling interval, which allows us to study diurnal cycles. In this article, we briefly introduce our monsoon research activities using these platforms. In addition, since our key platform research vessel “Mirai” retired her mission in December 2025, and JAMSTEC is now constructing a new Arctic research vessel “Mirai II”, we will also mention about the possibility of the new ship’s usage for monsoon research. Indeed, while her main mission is designed for Arctic research, her structure and equipped observation systems are adequate for other regions and missions including monsoon research.

Key words – R/V Mirai, ARV Mirai II, Autonomous surface vehicle, PHSMO.

1. Introduction

Since the contrast between conditions over the land and ocean is an essential factor for regulating monsoon systems, in-situ observation data over the ocean are highly required in spite of its limited resources compared to wide and long-term satellite-based data. For example, a ship can offer opportunities to deploy several measurement systems onboard that enable us to measure environmental conditions simultaneously from the ocean to even stratosphere. In addition, their data can be used to validate satellite data as well. Thus, combination of such data from in-situ and remote-sensing observations is required to understand large-scale phenomena like monsoons.

We at the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) have been conducting air-sea interaction study using the research vessel (R/V) *Mirai* (Fig. 1). By considering its limited observation time and space, we need to design an appropriate deployment of the R/V *Mirai* to capture targeted phenomena. For example, when we studied the initiation process of atmospheric convection associated with the Madden-Julian Oscillation (MJO; Madden and Julian, 1972) in the Indian Ocean, we formed an large ($O(1,000 \text{ km})$)-scale radiosonde sounding array with other ships and land-based sites in the central equatorial Indian Ocean for a couple of months (Yoneyama, *et al.*, 2013), as the MJO-convections often develop over the central Indian Ocean with 30-60-day interval and then it intrinsically propagates eastward along the equator. Namely, we could configure such a network based on statistical analysis of the MJO characteristics. Unlike an MJO event, however, monsoon research using a ship is a little bit challenging due to monsoon's broader and longer appearance features. Thus, strategic approaches are strongly required. For instance, when we conducted observations under the international field campaign program Years of the Maritime Continent (YMC, Yoneyama and Zhang, 2020), whose one main scientific topic is monsoons, a ship-based observation focused on shorter time-scale phenomena such as diurnal cycle of rain, while large-scale monsoon features were captured by land-based routine observations by the local meteorological agencies and satellite-based observations as well as reanalysis products (*e.g.*, Yokoi, *et al.*, 2017; Yokoi, *et al.*, 2019).

Fig. 2 demonstrates the recent R/V *Mirai* cruise tracks for air-sea interaction study in the tropical western Pacific. As indicated in different warm/cool colors, we conducted two types of cruise missions for air-sea interaction studies. One is to perform stationary observations for about one month to capture the features of atmospheric and oceanic conditions associated with targeted phenomena (indicated in red/pink colors), and the

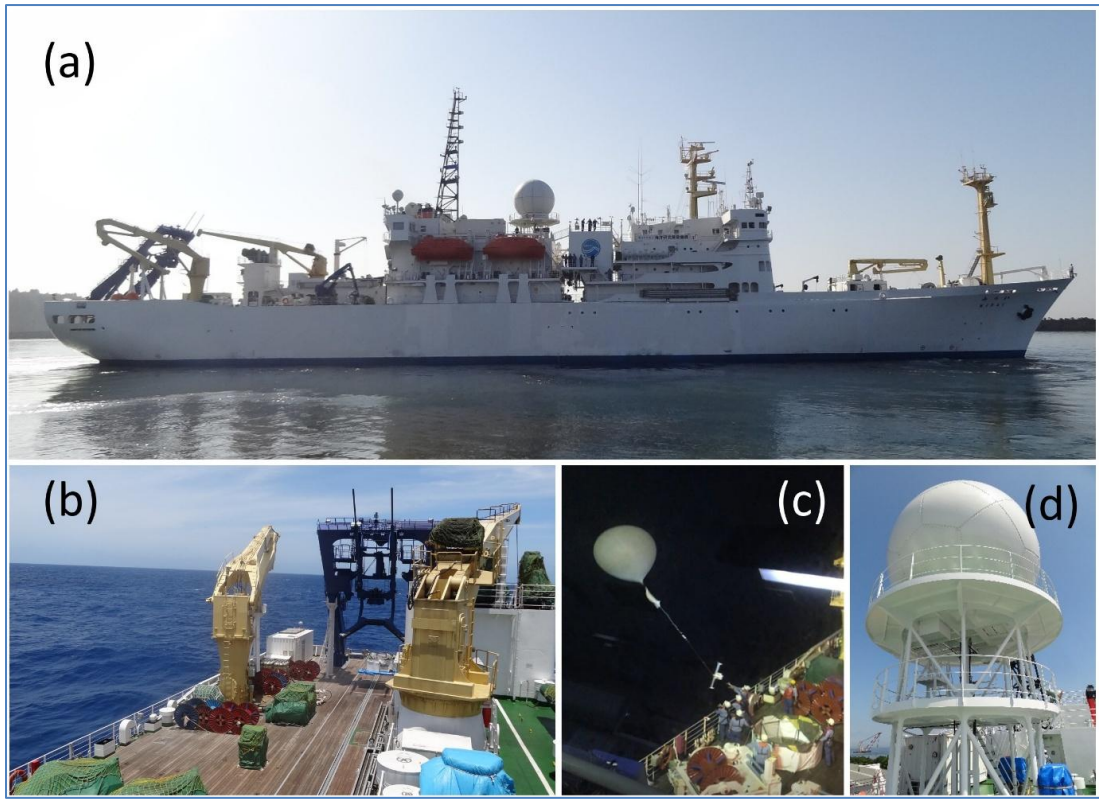
other is to deploy/recover a mooring for long-term monitoring (blue/green). In this article, we briefly introduce these measurement systems as a platform for monsoon research. Then, we explain our basic strategies of these observations to indicate how to contribute to monsoon research. In addition, whereas we refer the observations by the R/V *Mirai*, her mission has ended in December 2025. Instead, JAMSTEC is currently constructing a new research vessel that is expected to take over several *Mirai*'s missions. Thus, a short description of the new vessel will also be provided. The aim of this short article is to provide a tip to think about future international collaboration for monsoon research.

2. Data and observation

2.1. R/V *Mirai*

Research vessel (R/V) is the most basic platform for ocean-atmosphere system studies. The R/V *Mirai* (Fig. 1a) is equipped with various atmospheric and oceanic measurement instruments onboard as standard systems. As for atmospheric measurement, they include C-band polarimetric radar (Fig. 1d, details can be found in May, *et al.*, 2024), radiosonde, surface meteorology, ceilometer, while Conductivity-Temperature-Depth meter (CTD) with water samplers, Acoustic Doppler Current Profiler (ADCP), and sea surface monitoring system are used for measuring oceanic conditions. It is worth noting that these systems are maintained and operated by the exclusive marine technical staff, so that they can offer accurate quality-controlled data regardless to the cruise missions. Besides, since we adopt open data policy for data obtained using the R/V *Mirai*, data are available from JAMSTEC data site “DARWIN (Data and sample research system for whole cruise information in JAMSTEC)” at <https://www.godac.jamstec.go.jp/darwin/en/index.html> (accessed: 28 January 2026) or cruise project sites within 2 years from the completion of the cruise at the latest.

In addition to these standard measurement systems onboard the R/V *Mirai*, researchers can bring their own observation tools. For example, during the air-sea interaction study cruises, a Mie/Raman lidar is operated to monitor the vertical distributions of clouds, aerosols, and water vapor (Katsumata, *et al.*, 2020). Besides, since the R/V *Mirai* has a wide upper deck, radiosonde attached with several special sensors such as ozone, cloud particle counter, high accurate water vapor etc., which require large (about 2 m in diameter or more) balloon to ascend, can be launched (Figs. 1b and 1c). This is one advantage of large vessels. While normal radiosonde with 200 g balloon can reach around 25 km height at maximum, such special sonde with a large balloon can reach above 30 km. This special sonde can also be used for monsoon study.



Figs. 1(a-d). (a) R/V Mirai, (b) Upper deck, (c) Launch of special sonde from the upper deck, and (d) C-band polarimetric radar

During the MR21-03 cruise in May - July 2021 (light blue in Fig. 2), we launched ozone sondes 54 times to capture the material transport associated with large-scale Asian monsoon circulation. Fig. 3 demonstrates one example of ozone sonde observation, which was released at 13.3°N, 136.9°E on 12 June 2021. It shows anomalous high ozone partial pressure around 18 km height. This may indicate it captured the air mass transport from mid-latitudes, as such high value is shown only in a narrow vertical zone and cannot be explained by subsidence. Details on this feature can be found in Ogino, *et al.*, 2024. Indeed, they confirmed its air mass could be traced back to mid-latitude lower stratosphere (not shown here). This observation demonstrates that soundings of radiosondes attached with special sensor(s) and a large balloon, which can be performed over the ocean only from a ship with wide upper deck like the R/V Mirai, can offer the opportunities to capture large-scale circulation associated with monsoons and to provide insightful information with several parameters, as it measures atmospheric conditions from the ocean surface to lower stratosphere.

2.2. Autonomous surface vehicles

Previous subsection emphasized advantages of research vessel as a platform for various observation tools. However, while it is possible to obtain vertically dense

data, it is difficult to obtain data horizontally in space. As noted in Introduction, we usually form an adequate observation network under the international field campaign, so that we can expect participation of other ships. However, it does not guarantee that we can form such adequate arrays anytime, as such international coordination does not happen easily and frequently due to limited resources. Thus, recently we've initiated a new style in forming an observation array using not other ships but Autonomous Surface Vehicles (ASVs). Currently, we adopt "wave glider" as ASV, which is manufactured by Liquid Robotics Inc., USA (Hine, *et al.*, 2009). Wave glider converts ocean wave motion to propulsion power, and it is possible to put optional sensors onboard in addition to the standard surface meteorological measurement system (Grare, *et al.*, 2021). For example, we added Global Navigation Satellite System (GNSS) receivers during several field campaigns, so that we could obtain precipitable water vapor data (Fujita, *et al.*, 2020).

Fig. 4 shows the configurations of observation array for the two cruises (cruise code MR20-E01 in August - September 2020, and MR24-04 in June - July 2024). We deployed three ASVs around the R/V Mirai within a 50 km range, so that C-band polarimetric radar can cover the area surrounded by ASVs. Note that all ASVs were designed to cruise around the designated position within a

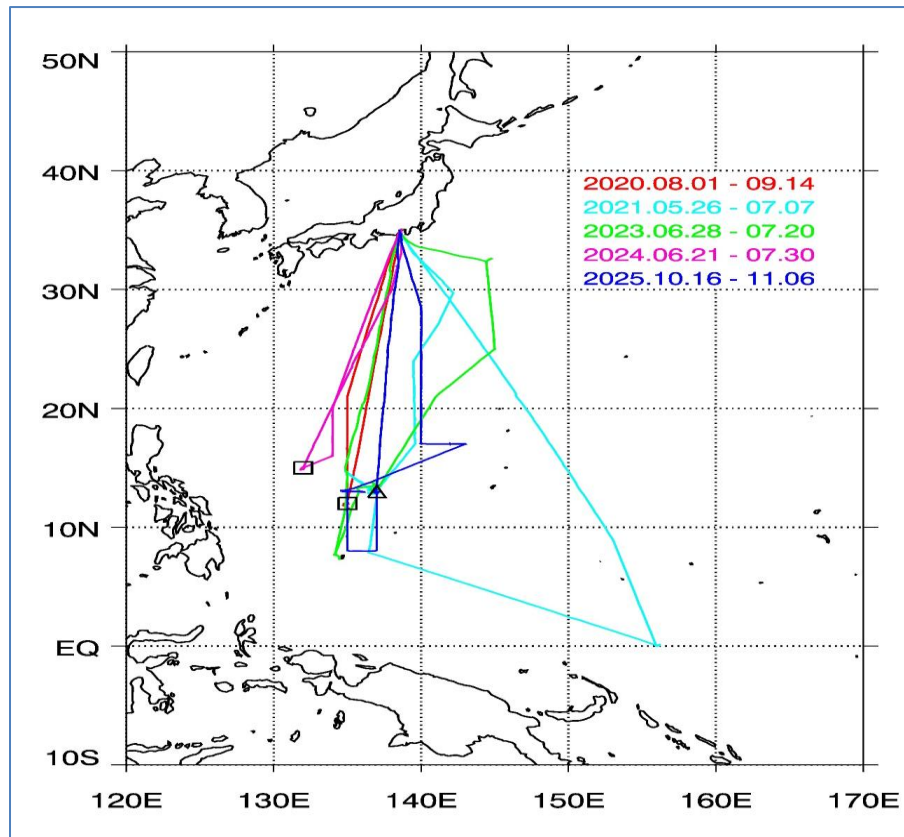


Fig. 2. Cruise tracks of air-sea interaction studies in the tropical western Pacific during 2020 - 2025. Solid squares indicate the stationary observation sites, while triangle shows PHSMO site

5 km range. So, the positions indicated in Fig. 4 show their mean locations during the on-station period. Both cruises aimed at studying the behavior of boreal summer intra-seasonal oscillation (BSISO), whose unique feature is northward propagation of convective area (e.g., Kikuchi, 2021), and several studies indicated that their northward propagation is related to the interaction between large-scale monsoon flow and meso-scale convective systems (Jiang, *et al.*, 2004; Bellon and Sobel, 2008). Thus, we decided to form such 100-km-scale array with ship and ASVs (and a mooring for MR20-E01). The advantage of this array is that it provides information about the gradient of several physical parameters. For example, Yoneyama, *et al.*, 2023 demonstrated that convergence deduced from sea surface temperature gradient and convective activity obtained from the C-band polarimetric radar have a significant relationship for the case observed during MR20-E01 (See their Fig. 8). Recently, Yokoi, *et al.*, 2025 estimated updraft mass flux across the boundary layer top using surface meteorological data obtained from all platforms and discussed how they behave during the tropical depression passage in the MR20-E01 cruise period. Moreover, Seiki, *et al.*, 2025 analyzed not only atmospheric data, but also oceanographic data (sea

temperature and salinity from CTD) obtained from the MR24-04 cruise. They demonstrated a relationship between surface heat flux and the oceanic mixed layer heat budget and then concluded that interaction between the oceanic mixed layer fluctuations and atmospheric convection development is key for the development of BSISO and its northward migration. These results support an observation strategy combining a ship with several ASVs is effective to study meso-scale convections associated with large-scale phenomena like BSISO and monsoons.

2.3. PHSMO

Since the warm pool region in the tropical western Pacific hosts a source for various climate systems including El Niño and the Southern Oscillation (e.g., Hasegawa and Hanawa, 2007), long-term monitoring of sea surface conditions is key for studying those phenomena. In particular, to monitor and capture the meridional shifts of northern edge of high sea surface temperature region, we have deployed a surface mooring called PHSMO, which stands for Philippine Sea mooring, at 13° N, 137° E since December 2016 (Nagano, *et al.*,

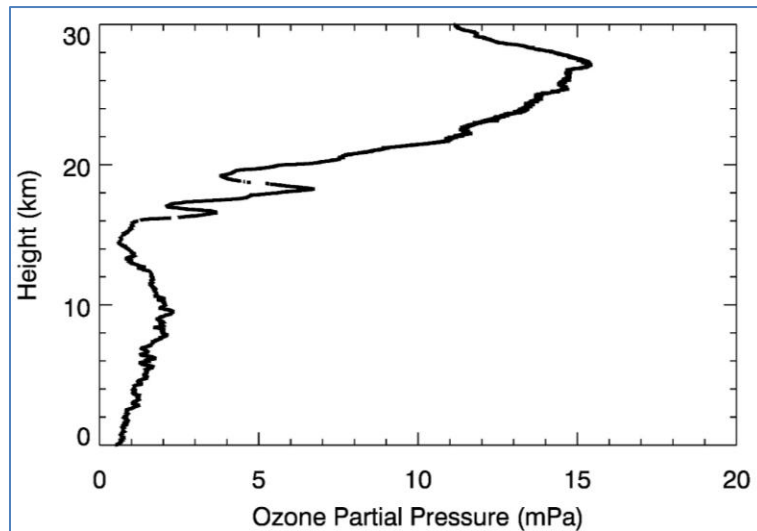


Fig. 3. Vertical profile of ozone partial pressure observed at 13.3°N, 136.9°E on 12 June 2021. Taken from the MR21-03 cruise report (JAMSTEC, 2021)

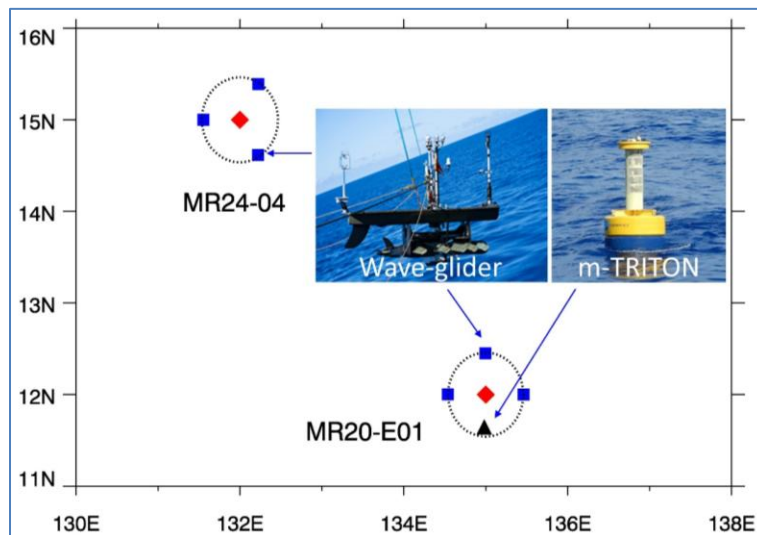


Fig. 4. Configurations of the stationary observation during the MR20-E01 (JAMSTEC, 2020) and MR24-04 (JAMSTEC, 2024) cruises. Red diamond, blue square, and black triangle indicate the nominal position of the R/V Mirai, ASVs, and m-TRITON buoy, respectively. Dotted line indicates the 50-km range from the Mirai

2018). This location is also critical for the Western Pacific Subtropical High, which affects the behavior of the Asian monsoon. PHSMO consists of surface meteorological sensors (pressure, air temperature, relative humidity, wind speed/direction, precipitation, short/long-wave radiation) and oceanic sensors (temperature, salinity, ocean currents, dissolved oxygen) down to 300 m depth (Fig. 5). Figure 6 is an example of time-depth cross section of sea temperature which demonstrates sub-seasonal (2 weeks ~) variation in addition to daily and sub-daily (mainly due to

tide) variations. PHSMO also takes the role of reference site for surface flux measurements and contributes to several international frameworks such as Tropical Pacific Observing System (TPOS, Smith *et al.*, 2019) and Observing Air-Sea Interactions Strategy (OASIS, Cronin, *et al.*, 2023).

While it is possible to utilize PHSMO real-time data for operational use (note that some of their data have been sent to meteorological centers through the Global

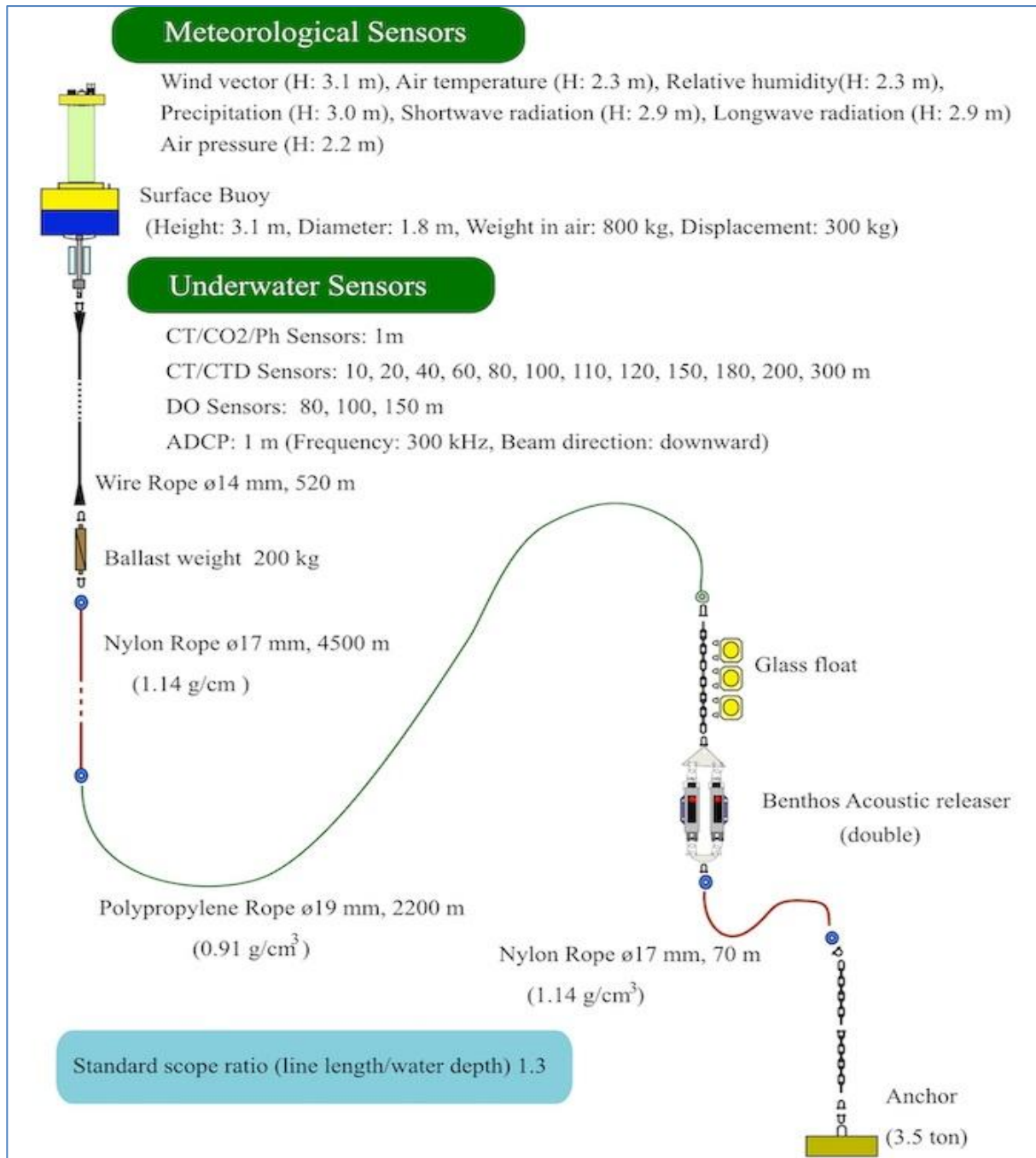


Fig. 5. Configuration of PHSMO. Taken from <https://www.jamstec.go.jp/ipobs/PhBuoy/> (accessed: 28 January 2026)

Telecommunication System), quality-controlled data have been available for scientific research purpose from their website at <https://www.jamstec.go.jp/ipobs/PhBuoy/> (accessed: 28 January 2026). For example, Seiki, *et al.*, 2023, which used PHSMO hourly data for 4 years from 2017 through 2020, found that the first BSISO event of the year appeared in early boreal summer (in May of 2018 and 2019) only when abrupt mean sea surface temperature

warming (about 2 °C per two weeks) along with the strong diurnal cycle was observed (see their Fig. 1 as well as Fig. 6 in this paper). This result demonstrates the advantage of long-term mooring with high resolution (hourly) data interval for climate research, because multi-scale interaction might be key for understanding those intraseasonal and seasonal phenomena. Besides, as shown by the recent work of Seiki, *et al.*, 2025, subsurface

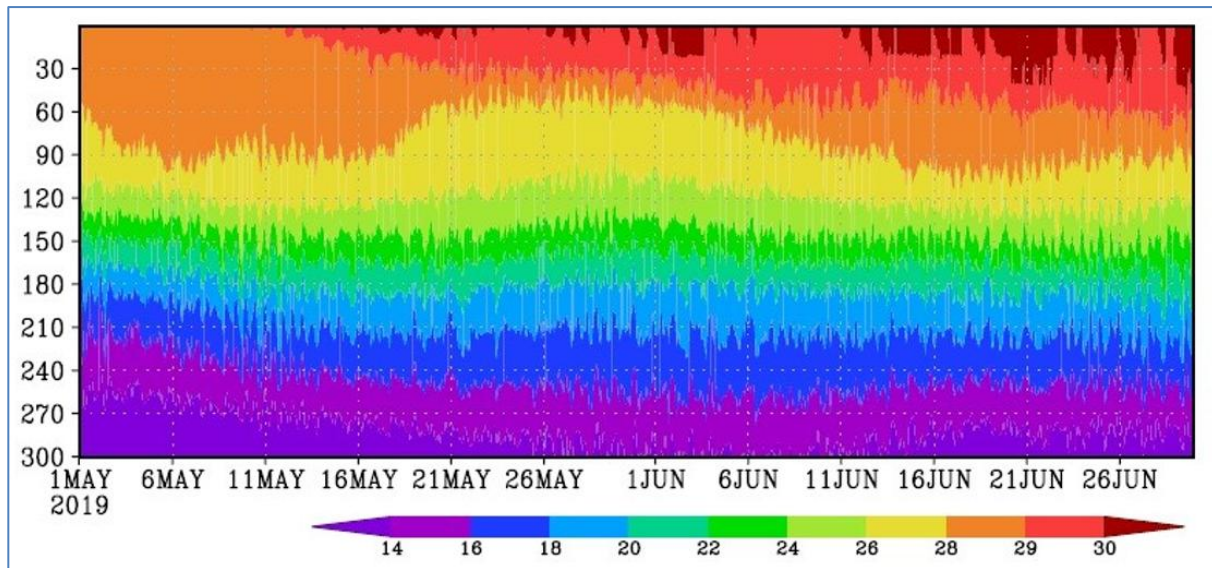


Fig. 6. Time-depth cross section of sea temperature obtained from PHSMO from May 1 through June 30, 2019. Shading interval is 2 °C except 29 °C to show the surface structure in detail

conditions are also responsible for sea surface temperature, and their variability affects BSISO behavior. Since mooring observations can provide ocean surface conditions in detail, their finding implies a possibility of improvement of BSISO onset prediction using PHSMO high-resolution surface and subsurface data that cannot be obtained from satellites.

3. Discussion

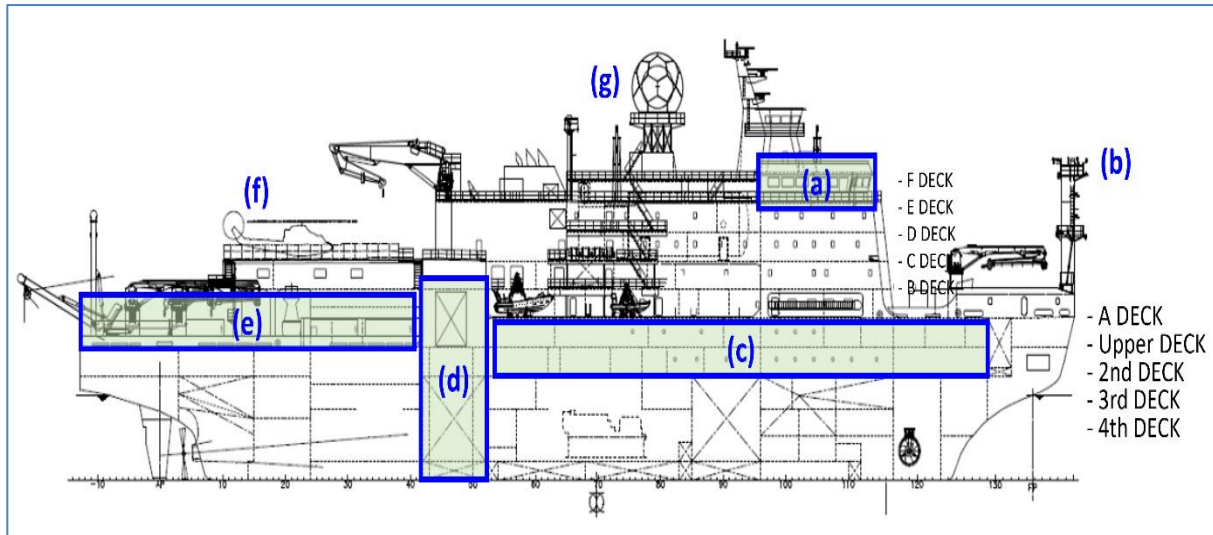
3.1. ARV *Mirai II*

Previous section introduced our current major platforms and demonstrated that combination among them is key to promoting monsoon research. However, the R/V *Mirai* has just retired in December 2025 after completing scientific cruises for 28 years since October 1997. Instead, JAMSTEC is currently constructing a new research vessel, and it is expected to be delivered to JAMSTEC by the end of 2026. Thus, a short description on this new ship is provided.

A new vessel will be an icebreaker, as her main mission is set to study Arctic Ocean, where it is very sensitive to climate changes. She is named the Arctic Research Vessel (ARV) *Mirai II*. While a ship itself is under construction, discussions on international collaboration have been made actively, since it is expected that the ARV *Mirai II* will be used as a platform for the Arctic Ocean research under the international coordination.

Table 1 shows several major specifications of the R/V *Mirai* and ARV *Mirai II*. The biggest difference is that only *Mirai II* has an ice-breaking capability. Thus,

Mirai II requires huge power for propulsion. Instead, it adopts dual fuel diesel engines, which use both liquefied natural gas and heavy oil, so that it can greatly reduce environmental impact. Note that Polar Class (PC) is defined by the International Association of Classification Societies (<https://iacs.org.uk/>) (accessed: 28 January 2026) and is classified into seven classes, which indicates possible cruise against sea ice conditions. Note that it does not indicate ice-breaking capability. PC 7 indicates it is possible to cruise only for summer/fall season in thin first-year ice, while PC 4 allows year-round cruise in thick first-year ice. So, the R/V *Mirai* did her Arctic Ocean cruises only in August–November period in the region where ice-breaking was not necessary. Here, one can notice that both vessels are of similar size and capabilities. Besides, the maximum speed of the ARV *Mirai II* is expected to reach 17 knots, while that was set to 16 knots for the *Mirai*. These similar points as well as their names are meaningful to be mentioned. This is because while the ARV *Mirai II* is designed suitable for Arctic Ocean research as her main mission, it also offers opportunities to use *Mirai II* for other missions in other regions including the Tropics as the R/V *Mirai* did. This is one important design philosophy of the ARV *Mirai II*. That is why we use the term “*Mirai*” for the new vessel. Thus, many of basic observation tools we used onboard the R/V *Mirai* will be equipped on the ARV *Mirai II*. They include C-band polarimetric weather radar, radiosonde semi-auto launcher, surface meteorological measurement system, ceilometer, GNSS receiver for precipitable water vapor measurement, ocean surface monitoring (temperature, salinity, dissolved oxygen, fluorescence, etc.), CTD with water samplers, ADCP, and so on. In particular, it is worth



Figs. 7(a-g). Provisional general arrangement of the ARV Mirai II. (a) wheelhouse, (b) foremast, (c) laboratory area, (d) CTD/moonpool, (e) observation deck, (f) helicopter deck, and (g) C-band polarimetric weather radar

TABLE 1

Major specifications of R/V Mirai and ARV Mirai II. Taken from JAMSTEC website at <https://www.jamstec.go.jp/e/about/equipment/ships/> (Accessed: 20 May 2026). Accommodation indicates maximum onboard personnel number, and “others” include researchers and technical staff. See the text for the meaning of Polar Class

	R/V Mirai	ARV Mirai II
Length	128.5 m	128.0 m
Beam	19.0 m	23.0 m
Depth	10.5 m	12.5 m
Draft	6.9 m	8.0 m
Gross tonnage	8,706 tons	13,000 tons
Cruising speed	11.5 knots	12.0 knots
Cruising range	12,000 nm	over 20,000 nm (planned)
Accommodation (crew/others)	80(34/46)	97(34/63)
Ice-breaking capacity	N/A	Capable breaking 1.2m of flat, one-year ice at 3 knots
Polar Class	PC 7	PC 4
Main propulsion system	Diesel (1,838 kW x 4) Electric propulsion systems (700 kW x 2)	Diesel (approx. 5,600 kW x 3) Dual Fuel Diesel (approx. 2,600 kW x 1)

noting that C-band polarimetric weather radar is a reused one from the R/V Mirai. Namely, it is possible to use the ARV Mirai II like the R/V Mirai in terms of technical viewpoint. Fig. 7 shows the general arrangement of the ARV Mirai II with indications of some key areas. Since it is now before its formal delivery to JAMSTEC, this diagram is temporary, but it will not be changed much. Most atmospheric measurement systems will be equipped

at the foremast, rooftop of or the rear outside of the wheelhouse. While the mooring systems will be deployed from the observation deck, special radiosondes such as ozone/precise water vapor sondes can be launched from not only the same deck but also the helicopter deck, when the helicopter is not onboard. One unique feature is a moonpool located at the inner side of the ship. While CTD casts are usually conducted from the upper deck at the

starboard side using a launch and recovery system, it is also possible to deploy it from the moonpool compartment in rough sea conditions. Research rooms are mainly arranged on the upper and 2nd decks. They include so-called dry/semi-dry/wet laboratories (for preparations of measurements and preliminary analyses), bio-geo-chemical analysis rooms, and water sample and sediment core storage rooms. Atmospheric chemical analyses for the air sampled at the foremast can be done in the laboratory at the most bow side on the upper deck.

At this moment, the details of operation style have yet to be determined, and we cannot guarantee the use of Mirai II for monsoon research. However, by considering her observational capability suitable for air-sea interaction study as shown in Table 1 and Fig. 7, we should think of her use as a platform under international coordination. Since its endurance at sea is expected to be around 45 days, which is the same number with that of the Mirai, it can cover enough duration for monsoon research.

4. Conclusions

This article briefly introduces our current and possible future observation platforms at JAMSTEC that can be used to contribute to monsoon research. We expect this might give a tip for their use under international coordination. This is the actual reason why the authors introduced our platforms at the 8th international workshop on monsoons. From the viewpoint of monsoon research, while PHSMO is expected to provide long-term ocean surface condition information related to the Asian monsoon, combination of a ship and ASVs must be strategically designed. So far, we have focused on the research of BSISO, but the selection of an observation site and period is always challenging. Thus, we may need to introduce more effective ways in designing an observation array to surely obtain necessary data for targeted phenomena. For example, incorporating artificial intelligence/machine learning technique into the design system might be one way. Further discussions are highly needed, and we hope this article contributes to such discussions.

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Author's contribution

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