Development of Offshore Monitoring Platform "SOLAReS" for SOLAS

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Abstract- Models of the atmosphere and ocean that integrate ecosystems are being developed so as to gain a higher level of understanding about current climate change and to predict further change in the future. However, it is difficult to evaluate these models until a sufficient quantity of long-term measurement data of slight changes in the atmosphere and ocean has been gathered. The time has come to conduct simultaneous, long-term observations of the atmosphere and ocean, focusing on the biogeochemical cycle between the atmosphere and ocean. This has involved advancing R&D of marine measuring and analyzing instruments and observation platforms. Based on such R&D, a plan to develop a frontier offshore monitoring system is being formulated. This will be one of the projects of SOLAS Japan contributing to international efforts. Our objective for the time being is to deploy a prototype on the waters off the Sanriku coast at the front of the Kuroshio and Oyashio currents.

I. INTRODUCTION

The following text is from the United Nations Framework Convention on Climate Change, as agreed upon at the Earth Summit (UNCED: United Nations Conference on Environment and Development) held in 1992:
"All Parties…shall…Promote and cooperate in scientific, technological, technical, socio-economic and other research, systematic observation and development of data archives related to the climate system and intended to further the understanding and to reduce or eliminate the remaining uncertainties regarding the causes, effects, magnitude and timing of climate change and the economic and social consequences of various response strategies..."

SOLAS (Surface Ocean – Lower Atmosphere Study), initiated in 2001 as a new international core project within the framework of the IGBP (International Geosphere-Biosphere Programme), maintains the following objectives:
"To achieve quantitative understanding of the key biogeochemical-physical interactions and feedbacks between the ocean and atmosphere, and of how this coupled system affects and is affected by climate and environmental change."

Models of the atmosphere and ocean integrating ecological systems are being developed so as to gain a higher level of understanding about current climatic changes and to predict further changes in the future. However, it is difficult to evaluate these models until a sufficient quantity of long-term measurement data of slight changes in the atmosphere and ocean has been gathered. The time has come to conduct simultaneous, long-term observations of the atmosphere and ocean, focusing on the biogeochemical cycle between the atmosphere and ocean. This has involved advancing R&D of marine measuring and analyzing instruments and observation platforms. Based on such R&D, a plan to develop a frontier offshore monitoring system is being formulated.

Observations conducted from this platform are intended for use in research of the following topics.

1) Research on the Exchange Process at the Air–Sea Interface: We aim to grasp temporal variations of atmospheric composition in aerosol and gases, the emission of biogenic gases from the ocean surface, and the chemical composition of seawater, while clarifying the factors affecting these variations. We also aim to clarify the relationships between these factors and variations in the amounts and types of organisms described in 2).

2) Research Related to Evaluating the Influence of Marine Ecological Systems: We aim to elucidate the variations over time in the composition of organisms inhabiting the sea surface as well as changes in the chemical constituents that greatly influence biological production. Combining these results with the results obtained in 1), we will evaluate the influence of variations in the amounts of chemicals on ecological systems, and in turn, the effect that the chemical components created by ecological systems has on the environment.

3) Research Related to Processes in the Ocean Boundary Layer: Movement of material through the air–sea interface is closely related to the conditions at the sea surface, and exerts a major influence on the biological habitat. This research will enable us to manage conditions of the ocean surface and biological habitat conditions and to take a quantitative approach to analyze the variations in chemical substances.

Therefore, this platform has been named SOLAReS (Surface Ocean – Lower Atmosphere Research System).

In Japan, ocean time series observations have been conducted in the higher latitudes of the northwest Pacific Ocean within the framework of JGOFS (Joint Global Ocean Flux Study), an international cooperative research effort. This observational fixed site, shown in Fig.1, referred to as "Station KNOT" (Kyodo North Pacific Ocean Time Series), is located at lat 44°N, long 155°E; observations have been conducted here from research vessels. However, long-term observations performed by vessels is difficult, as are observations in winter and under rough weather conditions. Thus, researchers have awaited the development of an unmanned, automated observation platform.

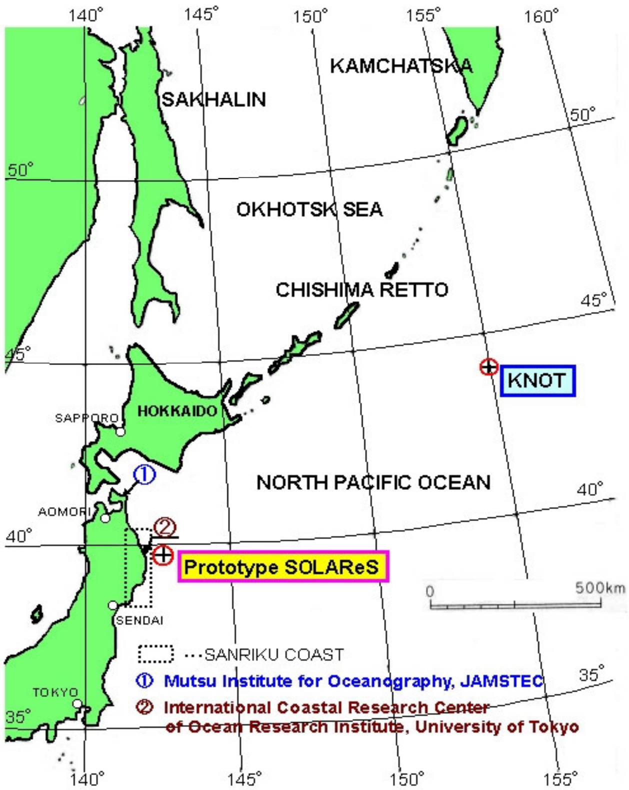


Fig.1 Station KNOT & Sanriku Coast

Plans for the development of SOLAReS follow the three steps below. The current aim is to embark on the first step.

1st Step: Development of prototype
2nd Step: Monitoring at Station KNOT
3rd Step: Global development

The region off the Sanriku coast has been proposed as the area where the prototype is to be deployed. This region is home to the International Coastal Research Center, Ocean Research Institute, University of Tokyo and the Mutsu Institute for Oceanography, Japan Marine Science and Technology Center (JAMSTEC). The locations of these centers are shown in Fig.1. Furthermore, this is the location of the confluence of the Kuroshio and Oyashio currents, making it an interesting region for interannual variation of oceanic phenomena by observational research as well.

II. PROTOTYPE SOLAReS

The following describes the characteristics of the prototype SOLAReS in terms of objectives.

1) We aim to develop and implement a marine observation platform that allows us to commence with integrated observations covering all fields related to marine physics, chemistry, and biology as soon as possible so as to advance research related to action of greenhouse gases at the air–sea interface.
2) Up to now, we have worked on developing various automated observation systems for biogeochemical study. We plan to enhance the long-term reliability, durability, and other qualities of these systems to make them suitable for deployment on the SOLAReS.
3) We are preparing a utility space to accommodate observational instruments currently used by researchers both inside and outside Japan.
4) Observations of weather, sea state, and buoy motion are to be provided by the buoy operator.
5) We aim to prepare the following buoy systems as a support system for the above observation instruments.
   - Electrical power supply
   - Seawater and air sample material supply
   - Observational data transmission
   - Observational instruments remote monitoring and control
6) In line with observation research activities, we aim to develop the observation instruments used in Station KNOT in the second step for greater reliability, reduced size and weight, and lower energy use, thus enabling the instruments to handle continuous unattended observations over the long term.
7) In addition to the above, we aim to conduct research and development of buoy systems (support systems) in the second step.

III. RESEARCH ACD DEVELOPMENT OF OBSERVATION SYSTEMS

At first, we conducted research and development of systems capable of continuous, unmanned *in situ* observation of chemicals in the atmosphere and seas, the analysis of which is manually carried out at present. The systems developed fall into two major areas.

One comprises *in situ* measurement systems, deployed on research and observation vessels and buoys and capable of conducting continuous on-site measurements of the chemical constituents of seawater and the air above it. Such systems include the three following apparatuses

- Seawater micro-flow nutrient analyzer
- Fourier transform infrared (FTIR) atmospheric trace gas analyzer
- pH profiler

However, since with current technology it is difficult to perform chemical and biological observations with automated *in situ* measurements, the following instruments was developed to allow samples to be retained while preventing any changes in the seawater so as to enable analysis at land-based laboratories.

- Automatic seawater sampling and freezing system

The above-mentioned four apparatuses were deployed on the Japan Marine Science and Technology Center's "Mighty-Whale" wave power generation testing facility as shown in Fig. 2 and used in on-site test observations.

We have also been working to develop improved technology for measuring CO_2 in the oceans. One cannot say that the measurement methods and devices used in different

Fig.2 Mighty-Whale

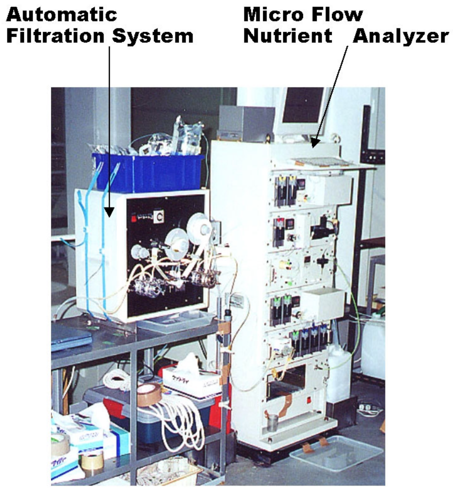


Fig.3 Seawater MicroFlow Nutrient Analyzer

countries throughout the world have been standardized internationally; indeed, this is currently a major issue. Thus, the two following measuring devices have been developed with the aim of bringing about international standards in measurement methods and the like.

- Marine CO_2 profiler
- High-sensitivity CO_2 flux meter

A. Seawater MicroFlow Nutrient Analyzer (Phosphoric Acid and Nitric Acid)

Compared to previous flow analysis methods, this device utilizes a micro flow (MicroFlow) method that reduces the amount of analytical reagents used by a factor of several tens. First, we conducted a basis test to determine the appropriate principles for measuring nutrient salts with this method and the optimal conditions for analysis. Based on these findings, we then produced a prototype device and conducted extended, continuous observational tests from Mighty-Whale. Our goal in testing for phosphoric acid was to achieve detection at a level 1/5 (0.2 µM) or less that of previous continuous automated measuring devices. The results show detection at levels below 0.1 µM [1]. Fig. 3 shows an exterior view of the device.

B. FTIR Atmospheric Trace Gas Analyzer

We designed and created a prototype FTIR atmospheric trace gas analyzer for continuous measurement of CO_2, CH_4, N_2O, CO, and O_3 in the ambient air. The purpose of this device was to measure CO_2 to a precision of 1 ppm. We built a trial FTIR system, with a white cell (optimized of long path

Fig.4 FTIR Trace Gas Analyzer

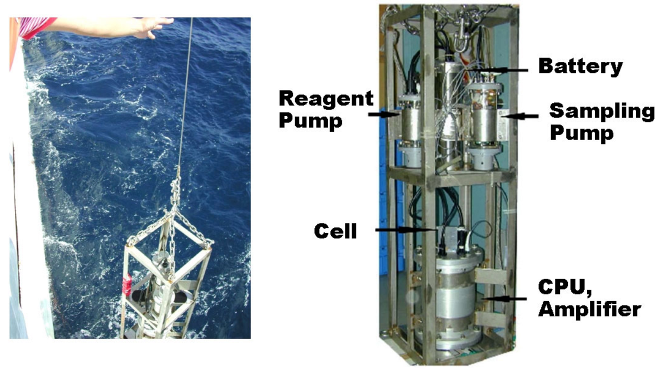


Fig.5 pH Profiler

gas cell length), and a detector without the use of liquid nitrogen. The system was designed to automatically collecting air samples and automatically pretreatment the dehumidified air samples at temperatures below –60°C.

We deployed the system on Mighty-Whale, ran an approximately 1-month operational test, and evaluated the performance of the system. After 20 repeated measurements, standard deviation for precision in measuring CO_2 was 1.1–1.3 ppm. Fig. 4 shows the apparatus deployed on Mighty-Whale.

C. pH Profiler

We constructed a test *in situ* pH profiler that utilizes a colorimetric pH measurement method that is at least one order of accuracy higher than conventional electrode-based methods. In this system, we used thymol blue, which is pH-compatible with seawater (7.5–8.5), as a pH indicator. A slight amount of seawater is added to this, and variations in color in the visible spectra of 400 nm and 700 nm are transmitted via optical fibers and measured with a spectrophotometer. This method was made possible by the MicroFlow method. This colorimetric method achieves an accuracy in measuring pH to within 0.001. Fig. 5 shows an exterior view of the device.

D. Automatic Seawater Sampling and Freezing System

We developed a system that it automatically collects and freezes seawater samples over a period of several months on the unmanned platform, for later on-land analysis. Under the expected operating conditions, eight water samples are collected simultaneously at 6-hour intervals one day a week, then put into 2-liter bags and frozen to –20°C and stored at that temperature. We also conducted field tests with this system deployed on Mighty-Whale. Laboratory analyses of the seawater from the sample bags have confirmed that, even 6 months later, samples remain unchanged and free of contamination when maintained in this frozen state. Fig. 6 shows a view of the prototype device.

Fig.6 Automatic Seawater Sampling and Freezing System

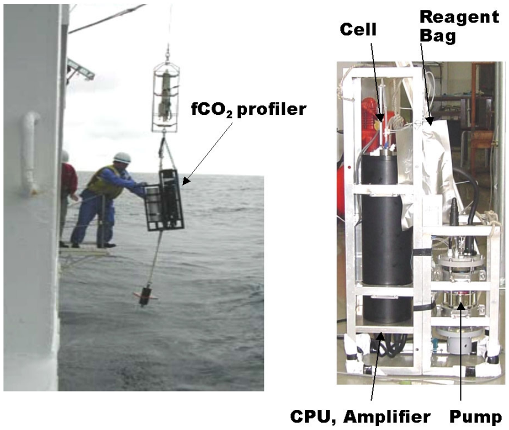


Fig. 7 Marine CO_2 Profiler

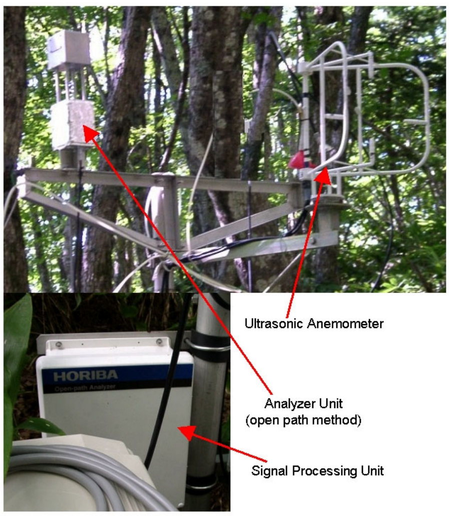


Fig. 8 High-Sensitivity CO_2 Flux Meter

E. Marine CO_2 Profiler

The marine CO_2 profiler system does not draw seawater with a pump and collector, but uses a submerged measuring system to measure CO_2 fugacity *in situ*. The prototype system, compact at 1 m in length and weighing approximately 40 kg, is a highly accurate apparatus pressure-resistant to a depth of 3000 m; it comprises a battery section, a pressure resistant housing (containing the CPU, light absorbance detector, and controller), a oil-filled vessel (liquid delivery pump), and a permeable membrane equilibrator. We first conducted basic performance tests in the lab using these devices. We then conducted pressure resistance tests, confirming that the system remained operational even at a depth of 3000 m. We later ran indoor tests to study optimal conditions, after which we ran a number of field tests, with good results [2]. From this we realized that we could expect the practical application of the world's first vertically oriented fCO_2 profiler. Fig. 7 shows an exterior view of the device.

F. High-Sensitivity CO_2 Flux Meter

Changes in the partial pressure of CO_2 in sea air are small, requiring sensors ten times more sensitive than ordinary CO_2 sensors on the market. We built a prototype open-path CO_2 sensor that uses a new type of light source, a tungsten lamp. We confirmed that the increase in the amount of light from the light source resulted in a 230% improvement in the signal-to-noise ratio, and that changing the infrared detector to a 3-stage cooled HgCdTe type unit improved the signal-to-noise ratio by 310%. We were further able to conclude that by optimizing the cell length in the design (improving both the electrical and optical systems), it is possible to attain a ten-fold increase in the signal-to-noise ratio.

Furthermore, in order to enable direct observation of CO_2 flux between sea and air from aboard the platform as it is rocked by the waves, an accelerometer is positioned at the same location as the measuring apparatus, allowing direct calculation of the anemometer's motion component. This incorporation of an ultrasonic anemometer in an open path method CO_2 sensor and the application of the eddy correlation method has enabled us to measure CO_2 flux directly, even from a moving platform. Fig. 8 shows an exterior view of the system.

IV. RESEARCH AND DEVELOPMENT OF THE BUOY SYTEM

Development of the SOLAReS buoy system involved three fundamental points:

1) Use of a wave-energy converter as the main source of electricity.
2) The ability of the platform to be detached and reconnected to its mooring on site.
3) Pumping up seawater over a continuous range from the surface to a depth of 300 m.

As the upper latitudes of the northwest Pacific feature an abundance of wave energy, we decided to use wave power generation as the main source of power for the unit. Moreover, in consideration of the difficulty of performing maintenance at sea, we designed the platform so that the platform could be brought into the base port alone, leaving the mooring back at the study site. In addition, our studies targeted the surface layer, which includes waters down to 300 m beneath the surface of the water. The basic elements comprising SOLAReS are shown in Fig. 9.

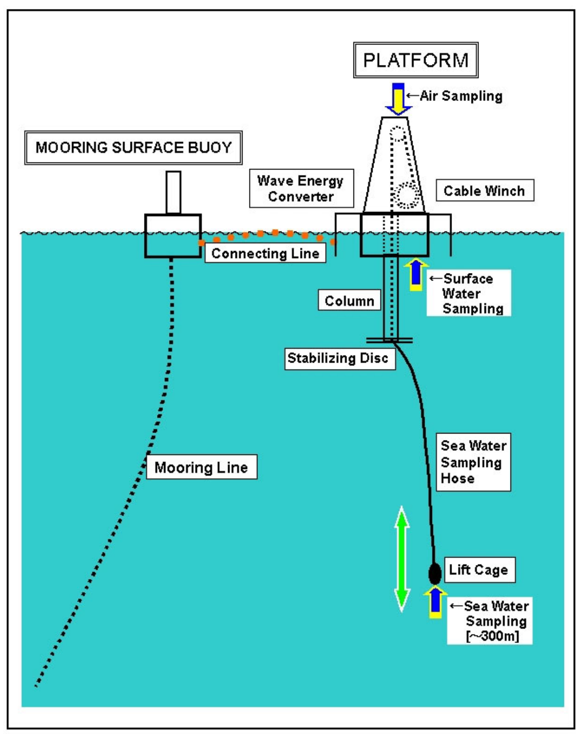


Fig.9 Components of SOLAReS

First, we set about making a rough design in order to produce an image of the SOLAReS for deployment at Station KNOT. The results are indicated in [3]. Fig. 10 is SOLAReS in rough seas at station KNOT. We then created the basic design of the prototype SOLARES. An outline of the prototype is shown in Fig. 11.

Fig.10 SOLAReS at Station KNOT

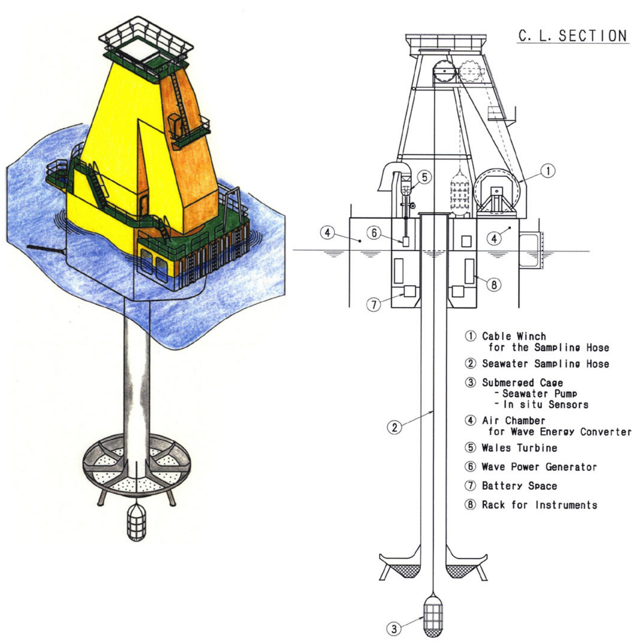


Fig.11 Prototype SOLAReS

A. Platform

We considered the following matters in studying the shape of the platform's floats.

- Suppression of wave motion
- High absorption of wave energy
- Small mooring force

Taking the above into consideration, we adopted the forms shown in Fig. 10 and Fig. 11 for the floating structure. In other words, the floating structure should be shaped so as to induce little resistance to currents in the surface layer. Furthermore, it should be provided with a submerged stabilizing disk to decrease the motion of the platform while allowing it to remain effective in absorbing wave energy. We performed tank tests to gain an understanding of the wave motion characteristics using this shape. In research and development related to the performance of wave energy absorption, we used numerical calculations in addition to tank tests. The results are presented in [4] and [5]. Fig.12 shows one view of the tank test.

We also developed a system to observe waves (wave amplitude, period, and direction) from measurements of the platform's motion. A large buoy such as SOLAReS does not conform to wave motion in short wave periods. References [6] and [8] provide an introduction to the results of this work. This system has been deployed on the "COMPASS" marine observation platform and is currently in use for wave observation.

B. Mooring System

Once a mooring system has been, it is extremely difficult in terms of sea-based operations to recover it for redeployment, making it desirable to leave it at the site throughout the observation period. However, since some heavy repairs of observation systems and other systems are difficult to perform at sea, we can anticipate the need to bring the platform to a base port. Thus, we designed the setup such that the platform alone can be brought back, leaving the mooring system, and the platform returned to the site and re-connected to the mooring after the necessary work has been completed.

Hanging from the platform is a seawater sampling hose that drops down 300 m into the water. The mooring line and this sampling hose must be kept separate. Since the range over which the platform shifts is not required to be strictly controlled, a single-point catenary mooring system was employed with a surface buoy suspending the mooring line as an independent system. Fig. 9 is an illustration of this system.

In researching this linked system consisting of the platform and the independent mooring system, we used both tank tests and numerical calculations to improve the accuracy

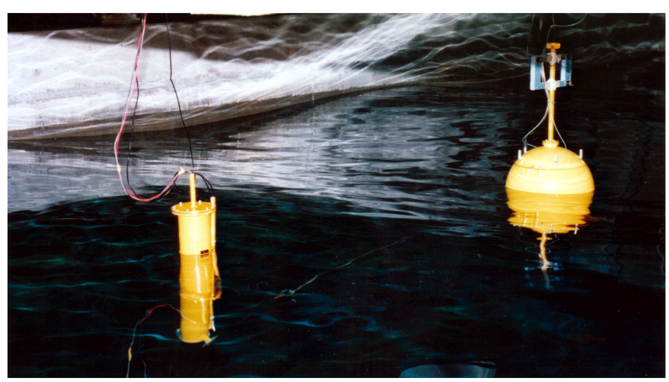


Fig.12 Tank Test of SOLAReS

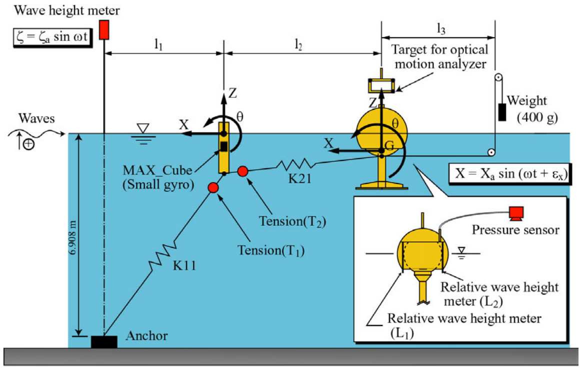


Fig.13 Experimental Setup

of estimates of the tension of the mooring line caused by the motion of the floating structures. The experimental setup is shown in Fig.13. The results of this research are provided in [7].

C. Electric Power System

The great amounts of electric power consumed by the observational instruments installed on SOLAReS makes the power supply a major issue. Located in the northwest Pacific Ocean, Station KNOT (at the 2nd step) is in a region of continually rough seas during winter, thus providing abundant wave energy from autumn to spring. However, while sea conditions are calm in summer, it is often foggy. Solar energy is thus deemed to be unavailable throughout the year. Accordingly, we selected wave energy converter as the main source of electrical power, even for the prototype.

Tests at sea of the wave-energy converter system with Wales turbines were conducted on Mighty-Whale (Fig. 2). Output of 50 kW was achieved during the tests, while the prototype SOLAReS is designed to use about 8 kW. Since there will be periods in summer during which power from wave generation is insufficient, the design includes a backup diesel generator to supply additional power. As above in "A. Platform," we conducted this research and development while carrying out tank tests with the aims of gaining a clear idea of the platform's ability to absorb wave energy and of increasing its efficiency.

D. Sea Water Sampling System

Considering that the sea surface boundary layer is 300 m thick, we investigated a system that pumps up seawater samples over a continuous range from the sea surface to a depth of 300 m. A cage containing a seawater pump and in-situ sensors was automatically raised and lowered, so as to allow continuous, vertically delineated observations. The seawater sampling hose constituted a complex cable including a Teflon tube, power cables, optical transmission cables, and tension strength members. A cross-section of this system is shown in Fig. 14.

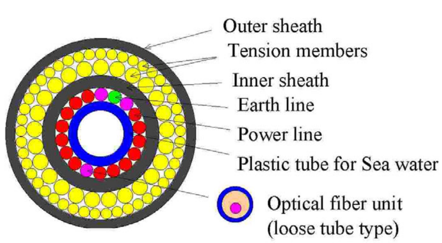


Fig.14 Cross-Section of Sampling Hose

Outer diameter of the hose is about 41mm and inner diameter of the tube for seawater is 10mm. A winch, in Fig. 11, with a drum of about 3 m diameter wound the sampling hose up and down the sampling hose. Seawater, electric power, and signals were linked to the platform through the slip ring assembly of the drum.

E. Broadband Radio Communication System

It should be vast amount of data when it is required to transmit motion picture of sea surface under the storm in addition to timely measured data for weather and sea conditions on the ocean. To solve this difficulty on the data transmission, we are developing a new marine radio communication system, Maritime Broadcloth Band Network (Sea Net). This system enables to connect between sea and shore with 2.4 GHz ISM (Industrial, Scientific and Medical) band. Followings are required specifications under the condition of maximum motion angle ±20°on a platform.

- Transmission rate : 10 Mbps
- Transmission : several dozen kilometers
- Transmission power : 10 mW or less

Meanwhile, we are proceeding to develop the high gain directional antenna which enables to connect mainland and small islands with long distance wireless LAN. To keep stable performance of the antenna on the sea, we have a plan to develop "Antenna Stabilization System" shown in Fig. 15 which is the system to correct/stabilize the antenna shake and antenna directivity.

Since communication charge using 2.4 GHz band with its power of 10 mW or below is cheaper than that using satellite communications and radio license is not required for the system, we intends to realize this convenient data communication system. Fig.16 shows the comparison between a satellite system and this system.

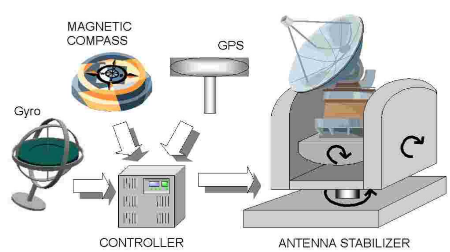
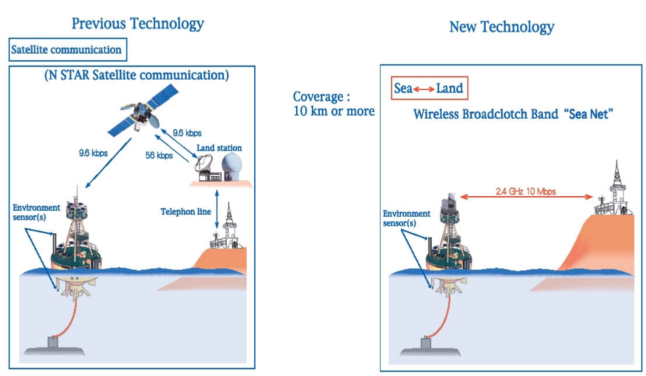


Fig.15 Antenna Stabilizing System



	Previous Technology	New Technology
Communication system	Satellite communication	Direct communication transmission
Transmission speed	9.6 kbps · 56 kbps	10 M bps
Data contents	Still picture	Movie picture available
Connection fees	Fixed charge : ¥5,000/month+communication charge : ¥1.5/sec.	¥600/month

Fig.16 Maritime Broadcloth Band Network

V. SUMMARY AND CONCLUSION

Human-induced climate change have already begun. We are now trying to model more accurate and precise estimates of global environmental changes with super computer such as the Earth Simulator. However, clarifying conditions at the boundary between the atmosphere and the ocean surface is indispensable in making such predictions. To this end, the SOLAS core project was launched with the main theme consisting of research on the reciprocal biogeochemical effects and feedback between the sea and atmosphere at the sea–air boundary.

Despite the number of different platforms devised thus far, all have been limited in the types of observational instruments they carry, and we have yet to come up with a platform that allows observation of parameters of biological and chemical conditions involved in phenomena occurring at time scales ranging from 1 hour to several days, months, and years, and the changes in these phenomena. In addition, while research on the movement of matter at the air–sea interface is underway, we have not clarified the phenomena at the air–sea interface, including the surface layer, where physical, chemical, and biological processes merge, nor have we obtained much of an understanding of these phenomena through solid observations of their effects at sea.

In consideration of this situation, preparation of advanced observational systems to accomplish integrated observations of the various biological, chemical, and physical phenomena occurring at the boundary between the sea and the atmosphere, along with research utilizing these instruments, is a necessary and urgent matter in predicting climatic changes.

Thus, our plan has the following objectives.

1) Development of a new platform providing basic functions by including improved versions of conventional ship-based observational instruments and other such devices now in use, as well as observational instruments currently under development.
2) Provision of a platform for continuous automated observations that can be available for domestic and foreign researchers, opening the door to the world so as to achieve a breakthrough in global long term oceanic observation.

Acknowledgments

We would like to acknowledge the support from the Japanese government in developing the measuring systems for biogeochemistry. Research and development of the seawater micro-flow nutrient analyzer, FTIR atmospheric trace gas analyzer, pH profiler, and automatic seawater sampling and freezing system were conducted in 1998 under contract with the New Energy and Industrial Technology Development Organization (NEDO). Research and development of the marine CO_2 profiler and high-sensitivity CO_2 flux meter were conducted in 2000 to 2003 under contract with the Japan Ocean Industries Association (JOIA) who contracted with the Ministry of Economy, Trade and Industry. We would like to express our gratitude for the support from each of these organizations.

Our thanks are also extended to Professor W. Koterayama, Assistant Professor M. Nakamura, et al at the Research Institute for Applied Mechanics, Kyushu University for their cooperation in the development of the platform. We also thank Fuji Electric Co., Ltd. (wave energy converter), Furukawa Electric Co., Ltd. (seawater sampling hose), and Taiyo Musen Co., Ltd. (broadband radio communication: SeaNet) for their cooperation.

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