Outline of New Cabled Observation System off Toyohashi

K. Asakawa, T. Yokobiki, T. Goto, E. Araki, M. Kinoshita and K. Mitsuzawa

JAMSTEC

Abstract - **A new cabled observation system off the coast of Toyohashi in central Japan is now being developed.**

The system uses a couple of former underwater optical telecommunication cables of about 60 kilo-meters long. The authors will use the cable in two ways simultaneously. One is to build a new observatory at the end of the cable. Underwater sensors including a broadband seismometer, a precise water-pressure sensor and an electro-magnetometer will be connected to the junction unit using underwater mateable connectors. The other is to use the same cable simultaneously as a long emitting antenna to monitor the electro-magnetic property of the earth crust.

We have developed a new time synchronization system. It provides precise 1PPS signal, clock and NMEA data to underwater sensors.

In this paper, we will describe the outline of the system. The longterm monitoring will start in this April.

I. INTRODUCTION

A new cabled observation system is now being developed [1]. It is located off the coast of Toyohashi in central Japan. It is an important area for geophysical study because huge earthquakes have occurred periodically in this area due to the movement of plate boundaries, and it is close to heavily populated cities. This paper will describe the outline of the system. The scientific purpose of this project will be presented by another accompanying paper.

The system uses a couple of former underwater optical telecommunication cables of about 60 kilo-meters long shown in Fig.1. The cables were a portion of domestic telecommunicatiaon cable network called Japan Information Highway (JIH) which was developed by KDD in 1996 [2]. It uses new technologies of dense wavelength division multiplex (DWDM) and optical amplifier which enables to make flexible and wideband communication system.

These cables connected Toyohashi to Shima and Ninomiya which is located close to Tokyo. In 2003, the power feeding line of the east-side cable was damaged and shorted to the ground. As it was the best season for fishery, it was difficult to immediately repair the fault point. Then KDDI abandoned the landing segments off Toyohashi and the landing station, and bypassed the landing cables by connecting two cables from Shima and Ninomiya offshore. As the cables are placed where big earthquakes take place periodically, and scientific observation is needed, JAMSTEC took over the cables and the landing station (Fig.2) from KDDI in 2006.

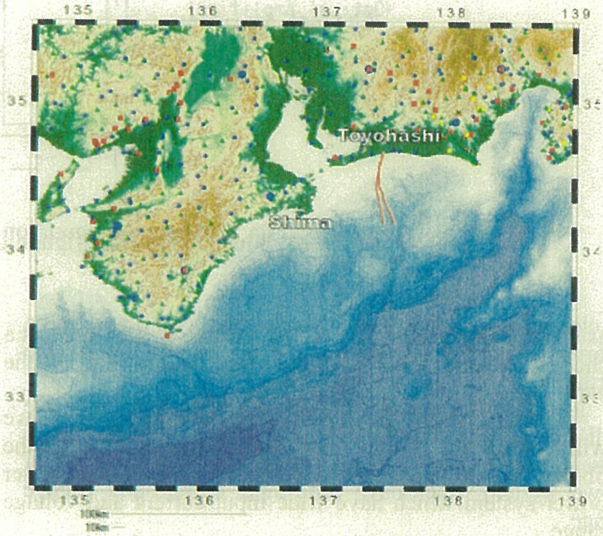

Fig. 1 A couple of cables to be re-used for scientific observation

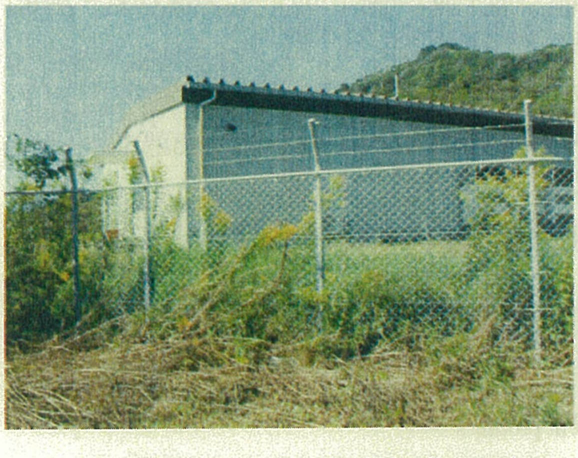

Fig. 2 View of the Toyohashi landing station

The authors will use the west-side cable in two ways. One is to build a new observatory at the end of the cable, and the other is to use the cable as a long emitting antenna for low-frequency electro-magnetic waves. The latter is to monitor the electro-magnetic property of the earth crust which reflects the content of water. As there is only one conductor in optical telecommunication underwater cables, and the return current flows in sea water, we can use cables

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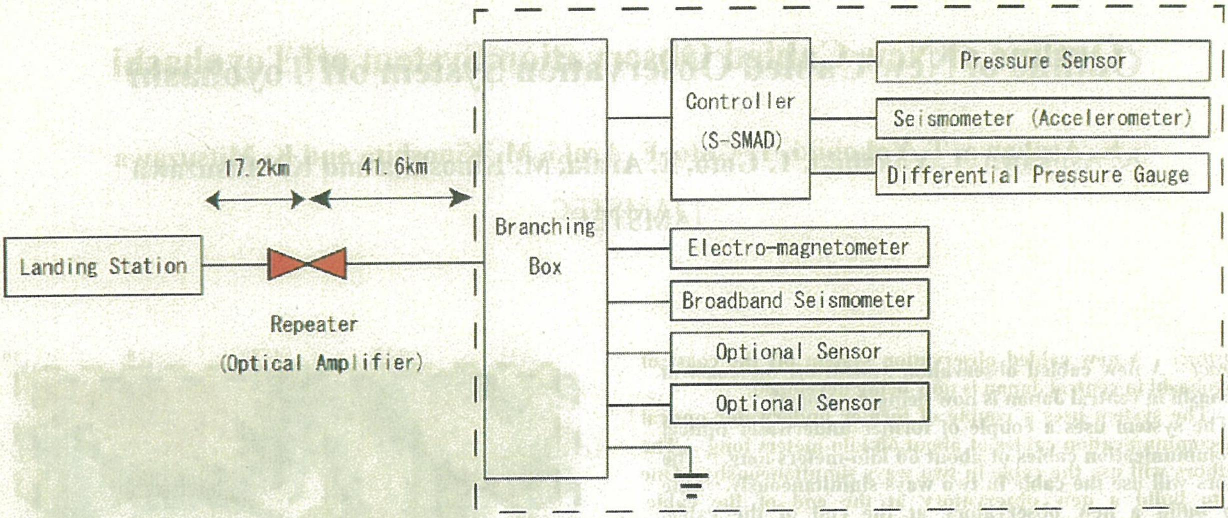

Fig. 3 Basic configuration of the off-Toyohashi system

as electric antennas. The east-side cable will be used as a shorter antenna for electro-magnetic monitoring of the earth crust.

In order to use the cable as an emitting antenna, we will control the supply current and the voltage to the observatory. We have developed a new underwater power system which have wide input current and voltage range.

We have also developed a new time synchronization system. It provides 1PPS signal, clock and NMEA data to underwater sensors. NMEA data are provided by GPS receivers and denote status of GPS receivers. The 1PPS signal will be used for acoustical geodetic monitoring systems and the clock will be used for crystal water-pressure sensors for example.

Transmission delay in the underwater cable is measured on a landing station using 1PPS signals that are turned back in an underwater unit. The measured transmission delay is forwarded to the underwater unit and is used to compensate the transmission lag.

We have confirmed that the system can provide a precise 1PPS signal with Alan deviation of 10^{-11}.

We will deploy the junction unit in this March, and will connect sensors in coming April. The long-term monitoring will start just after the connection of sensors.

We have already reported the outline of the off-Toyohashi system at SSC'06 [1]. In this paper, after reviewing the outline of the system, we will report the recent progress.

II. OUTLINE OF THE OFF-TOYOHASHI SYSTEM

Fig. 3 shows the basic configuration of the off-Toyohashi system [1]. At the end of the west-side cable, a junction unit (Fig. 4) will be connected. There are five underwater mateable connectors on the junction unit. A seismometer, a precise water-pressure sensor and an electro-magnetometer will be connected to the junction unit. Two additional underwater mateable connectors are provided for additional sensors. Fig.4 shows a photo of the junction unit. A watertight housing is connected directly to the end of the stub cable through a gimbal joint unit. All the electronics including an underwater power unit, electro/optical converters, Ethernet hub, a monitor/control unit and a precise clock and synchronization unit are installed in the housing. The stub cable will be connected to the main underwater cable using a universal joint. As the universal joints are widely used in the telecommunication cable industry, and their specification and method of assembly is standardized, the connection on cable ships is certain and reliable.

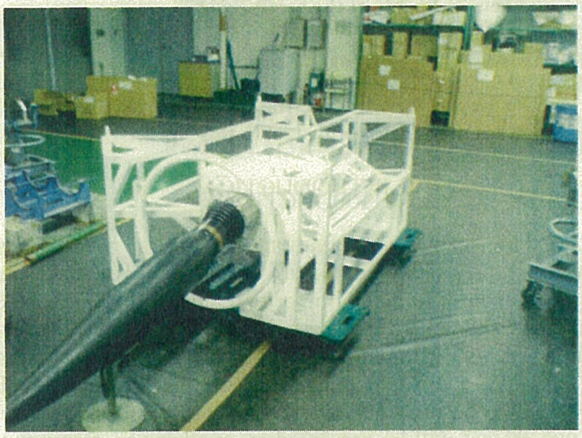

Fig. 4 Photo of the junction unit

Before Underwater mateable connectors were mounted.

Electric power, data communication line and clock/synchronization signal will be provided to sensors through underwater mateable connectors. The maximum available electric power to each sensor is +15V/1A.

The communication protocol between the landing station and the junction unit is Ethernet. Therefore the system can easily be connected to the terrestrial IP network. 10Mbps Ethernet or RS422 can be chosen for data communication interface with sensors.

III. POWER FEEDING SYSTEM

As the power feeding system has already been described in the previous papers [3], we only explain the outline of the system here.

As already mentioned, we are going not only to deploy a new observatory at the end of the cable but also to use the cable as a long emitting antenna to monitor the inner electromagnetic properties of the earth crust. By controlling the supply current flowing in the cable, we can emit a very-low-frequency electromagnetic field. The cable acts as a long emitting antenna.

There is a repeater installed in the west-side cable as depicted in Fig.3, which restricts the current to 0.92A. In order to avoid this restriction, we apply a current with an opposite polarity to the normal operation. As the power supply circuit in the repeater basically consists of zener diodes as shown in Fig. 5, by applying a current with the opposite polarity, we can inactivate the repeater, and can vary the value of the current.

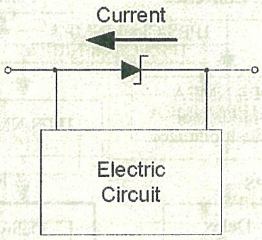

Fig. 5 Basic equivalent power supply circuit in repeaters

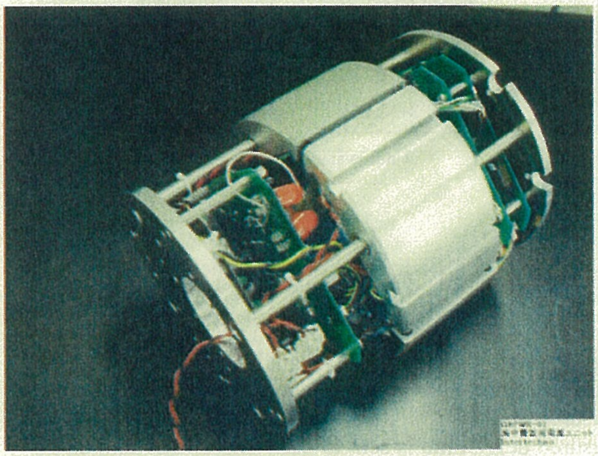

Fig. 6 Photo of the underwater power unit

We have developed an underwater power unit (Fig. 6) which has wide input voltage/current range in order to widen the range of the supply current. Table 2 show the Estimated power consumption of the underwater devices, and Fig. 7 shows the input range of the underwater power unit. Input current range depends on the output power: when the output power is at maximum (108W), we can vary the feeding current from 0.5A to 1.3A for example.

Table 2 Estimated power consumption of the underwater devices

Devices	Estimated Power Consumption (W)
Transmission equipment	16.5
Power system controller	6.3
Time-synchronization and clock	24.0
Sensors	
Broadband seismometer	6.0
S-SMAD	12.0
Electro-magnetometer	3.6
Optional-1	15.0
Optional-2	15.0
Others	10.0
Total	108.4

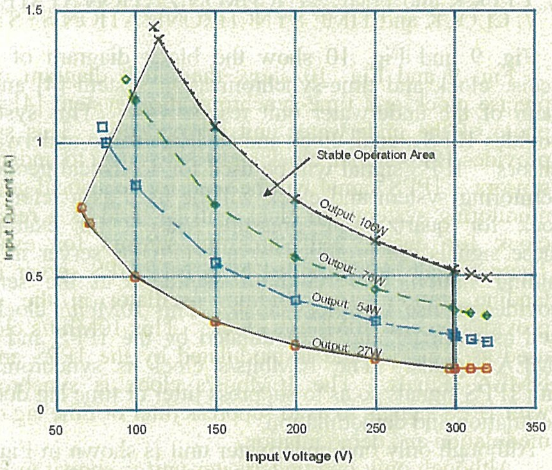

Fig. 7 Input range of the underwater power unit with a parameter of output power

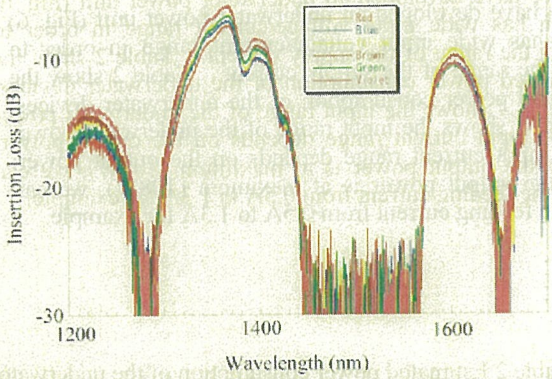

Fig. 8 Optical insertion loss of repeaters

IV. OPTICAL TRANSMISSION SYSTEM

As there are three fiber pairs in the cable, we have decided to make three optical data transmission channels; (a) Ethernet, (b) clock and time-synchronization and (c) control and monitor of power feeding system.

The optical amplifiers in the repeater are inactivated and act as optical absorbers as the current is supplied with the opposite polarity. Fig. 8 shows the spectrum of optical insertion loss measured with optical spectrum analyzer using a spare repeater. It can be found that the insertion loss at 1,610nm is less than 12dB. Assuming the transmission loss of the optical fiber at 1,610nm being 0.23dB/km, the total loss of the transmission becomes 25.6dB. As the wavelength of 1,610nm is one of the wavelengths used for coarse wavelength division multiplex (CWDM), various optical converters can be commercially available which have enough transmission loss margin. For clock and time-synchronization channel, a converter which can transmit 10Mbits/s is used. For the control and monitor of power feeding system, a RS422 converter is be used.

V. CLOCK and TIME SYNCHRONIZATION SYSTEM

Fig. 9 and Fig. 10 show the block diagram of the precise clock and time-synchronization system [4] and a photo of the underwater unit respectively. This system provides 1PPS signal, clock and NMEA data to underwater sensors. 1PPS signal will be used for acoustical geodetic monitoring system and clock will be used as a reference clock for quartz water-pressure sensors for example. These signals are provided by a NTP/GPS server in the landing station. A rubidium oscillator in the server provides precise 10Mbits/s clock. This 10Mbit/s clock is used as a carrier and is modulated by the 1PPS and the NMEA signals. The 10Mbits/s clock is synchronized with 1PPS signals so as to suppress jitter or time lag due to modulation and demodulation.

Although only one underwater unit is shown in Fig. 9, the system can support up to 64 underwater units, so that we can deploy many acoustical geodetic monitoring systems on the seafloor. Each unit has an unique address and can be controlled individually.

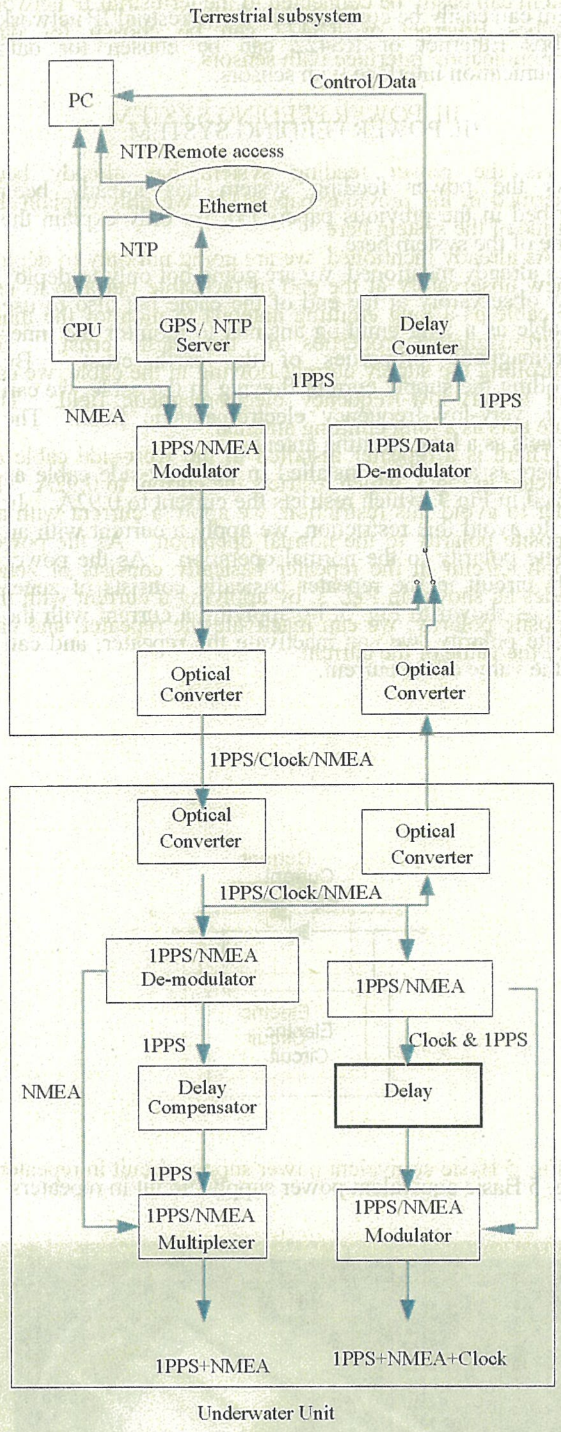

Fig. 9 Block diagram of time-synchronization

A loop-back circuit is installed in each underwater unit (Fig. 9), and the loop-back signal is sent back to the terrestrial subsystem on command. The delay counter measures the transmission delay. The information on measured delay time is sent to each underwater unit and is used to compensate the transmission delay of the 1PPS signal. As the delay compensator, which is imbedded in

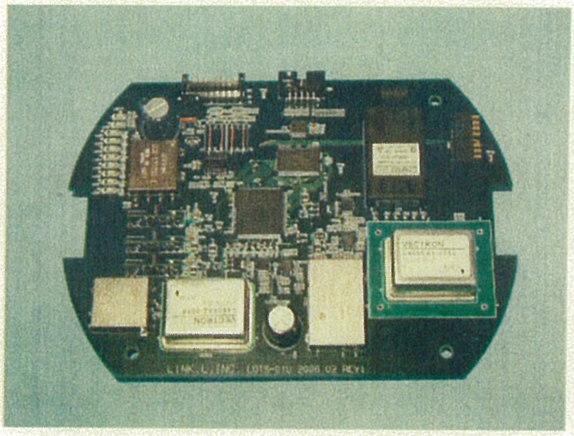

Fig. 10 Photo of the underwater unit

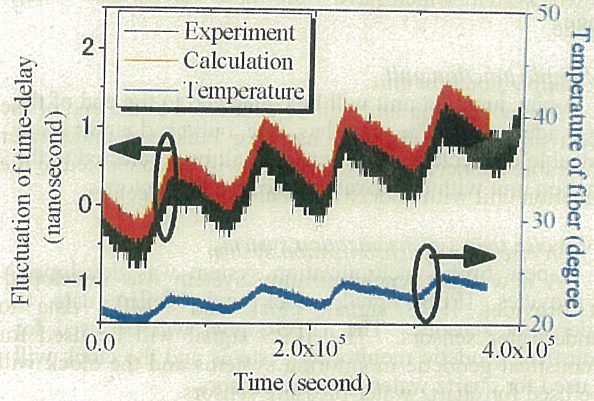

Fig. 11 Comparison between transmission delay fluctuation and room-temperature fluctuation

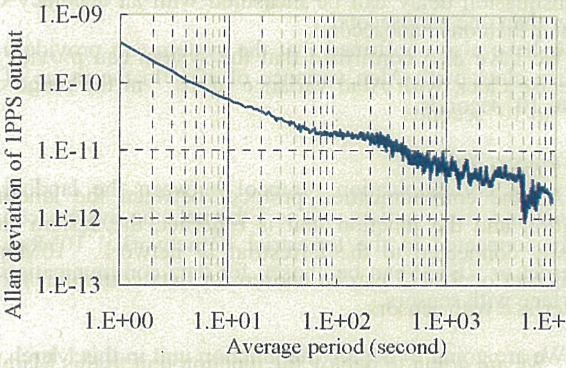

Fig. 12 Allan Deviation of 1PPS output

the FPGA, is running with 100Mbits/s clock, we can compensate the delay time with 10 nanosecond resolutions.

The optical signal from the terrestrial system contains 64 NMEA data that correspond to each underwater unit. In the underwater unit, 1PPS/NMEA de-multiplexer separates all the NMEA data from the signal. After the delay time is compensated, a NMEA data corresponding to the unit is added to the signal.

Two kinds of outputs to sensors can be chosen. One is 1PPS plus NMEA data. The electric interface is RS422. The other is 1.25 Mbits/s clock modulated with 1PPS and NMEA data.

We have conducted several evaluation tests. We used two 10km single mode fibers for the up and down link.

Fig. 11 shows the comparison between the delay-time fluctuation and the room temperature fluctuation over four days [4]. As the calculated delay-time fluctuation (red line) using the room temperature well coincides with the measured delay-time, we can confirm that the main cause of the delay-time fluctuation for 1PPS signal is temperature fluctuation. We can also confirm that the transmission delay can be measured with an accuracy of better than one nanosecond.

Fig. 12 shows Allan deviation of the 1PPS signal delivered to sensors [4]. Allan Deviation given by (3) is commonly used to indicate the stability of clock or frequency.

$$\sigma_y(\tau)=\sqrt{\frac{1}{2(M-1)}\sum_{i=1}^{M}\left(\overline{y_{i+1}}-\overline{y_i}\right)^2} \qquad (3)$$

Where

$\overline{y_i}$: A set of measured frequency averaged over period of τ
M: number of data

We can confirm the stability of better than 10^{-11} in the range of 10^3 to 10^4 seconds. Although a little degradation due to transmission is found, we can confirm enough stability of 1PPS signal for acoustical geodetic monitoring systems.

IV. CONCLUSIONS

In this paper, we report the outline and the recent progress of the new cabled observation system being developed off the coast of Toyohashi in central Japan. It is an important area for geophysical study because huge earthquakes have occurred periodically due to the movement of plate boundaries, and it is close to heavily populated area.

The system has the following new features.

A. Method of usage

We will use the cables in two ways. One is to build a new observatory at the end of the west-side cable, and the other is to use the same cable simultaneously as a long emitting antenna for low-frequency electro-magnetic waves. The latter is used to monitor the electro-magnetic property of the earth crust which reflects the content of water.

In order to use the cable as an emitting antenna, we will control the supply current and the voltage to the junction unit. We have developed a new underwater power system which have wide input current and voltage range.

B. Simple junction unit

A new junction unit will be connected to the end of the west-side cable. The unit has five bulkhead underwater mateable connectors. All sensors will be connected to the junction unit with underwater mateable connectors.

C. Precise time synchronization system

A new time synchronization system was developed. It provides 1PPS signal, clock and NMEA data to underwater sensors. The 1PPS signal will be used for acoustical geodetic monitoring systems and the clock will be used for quartz water-pressure sensors.

Transmission delay in the underwater cable is measured on a landing station using returned 1PPS signal back from an underwater unit. The measured transmission delay is forwarded to the underwater unit and is used to compensate the transmission lag. We confirmed that the transmission delay can be measured with an accuracy of better than one nanosecond.

We have also confirmed that the system can provide a precise clock with Alan variance of 10^{-11} in the range of 10^3 to 10^4 seconds

D. Ethernet link

As the communication protocol between the landing station and the junction unit is Ethernet, the system can easily connected to the terrestrial IP network. 10Mbps Ethernet or RS422 can be chosen for data communication interface with sensors.

We are going to deploy the junction unit in this March, and will connect sensors in April. The longterm monitoring will start just after the connection of sensors.

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