Recovery of an ice buoy at 60°S in the Southern Ocean

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***Abstract*— Performing oceanographic measurements from the sea surface to the sea bottom is technically challenging under rough or icy sea conditions. In 2011, we tested measures for protecting a buoy under such severe conditions by incorporating anti-icing and tolerance to high winds and rough seas. Based on those results, we conducted detailed design of a suitable buoy system. In January 2012, we deployed the buoy in the Southern Ocean off the Adelie Coast at 60°S and 140°E. After 11 months on December 2012, we recovered all the mooring gear that we had deployed. This report describes the mooring system recovery operation and the data acquisition rate. Moreover, we provide some highlights of data found in addition to some data deficits. We infer the reasons why we were unable to sample some of the data from analyses of the data we gathered.**

Keywords— oceanographic observation; mooring; icing; rough sea

I. Introduction

The ocean off the coast of Antarctica, a region of cold, heavy Antarctic Bottom Water formation supplies bottom and deep water to oceans around the world. It is an atmosphere-heating region because it releases large volumes of heat to the atmosphere in the course of deep-water formation. Changes in the deep-water configuration are closely related to phenomena of global warming and other climate changes [1].

Off the Adelie Coast, mooring of surface buoys that can measure the air-sea flux in these waters are expected to be ideal for verification of events and hypotheses that have been derived from observations obtained with ship-borne devices in Antarctica coastal regions and through related data analyses [2, 3, 4, 5]. Establishment of a continuous meteorological observation network is also regarded as highly desirable by the Southern Ocean Observation System (SOOS) and other international scientific organizations, particularly in regions of "data blanks" where little or no meteorological data have been obtained. Because of the harsh environment of rough seas and low temperatures, however, surface buoy mooring south of 60°S latitude has not been practicable. If problems posed by this environment can be resolved through technological development to enable surface-buoy mooring and acquisition of time-course data on interrelated oceanic and atmospheric changes, such data might contribute to breakthroughs in research related to global environment observation, assessment, and prediction.

At JAMSTEC, through application and modification of technology developed for existing moored buoys, we are developing a Southern Ocean surface mooring system for the purpose presented above. JAMSTEC has currently moored and operated nearly 20 buoys of two types in equatorial regions of the Pacific and Indian oceans: the TRITON taut-moored buoy and the m-TRITON small slack-moored buoy. The latter carries meteorological sensors for wind speed and direction, air temperature, humidity, short-wave radiation, rainfall, and atmospheric pressure, in addition to underwater sensors for water temperature, salinity, depth, and flow velocity. The Southern Ocean surface buoy was developed based on the m-TRITON, with particular ease of deployment and recovery because of the limited number of observation ships that sail to Antarctic waters.

II. Features of the Southern Ocean buoy system

A. *Design of the Southren Ocean buoy system*

The Southern Ocean has rough seas and icy conditions. Therefore we added countermeasures against rough seas and icing to the existing m-TRITON system [6, 7].

Fig. 1 shows the float of the Southern Ocean buoy system we have developed based on the m-Triton. As countermeasures for rough sea conditions, we applied a static analysis program used previously in designing the m-TRITON system. The analysis input included the assumed conditions of a 25 m/s wind speed at the float based on earlier report [8]. The vertical underwater profile was based on the 2001 vertical profile of current in the ocean general circulation model OFES at the buoy deployment site, with a bias added to obtain a bottom current of 40 cm/s, which presents the fastest bottom current speed observed by well-experienced researchers in the Southern Ocean. To withstand the forces found through that analysis, the mooring line constituent materials were the following: 16 mm diameter wire rope, 7×7 string, 64.4 kN (6.5 tonf) breaking load, □ 17 mm diameter nylon rope, string 8 strand, 70.0 kN (7.1 ton·f) breaking load, □ 19 mm diameter polypropylene rope, string 8 strand, 59.0 kN (6.0 ton·f) breaking load, and as hardware, shackle 22 right under the float, shackle 18, and swivel AB-102. For a water depth of 4,500 m, the total rope length is 5,994 m for 4,500 m water depth. The scope ratio was therefore 1.33.

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For icing, we fitted a housing at the main pole on the float to protect a thermometer / humidity sensor and a barometer from sea spray and icing. Furthermore, for measuring wind speed, we fitted two wind speed sensors attached outside the housing. One was equipped with a 100 W micro-heater on its transducers. The heater was turned on when the air temperature was below -0.5 °C considering supercooling. We expected to melt icing on the transducers.

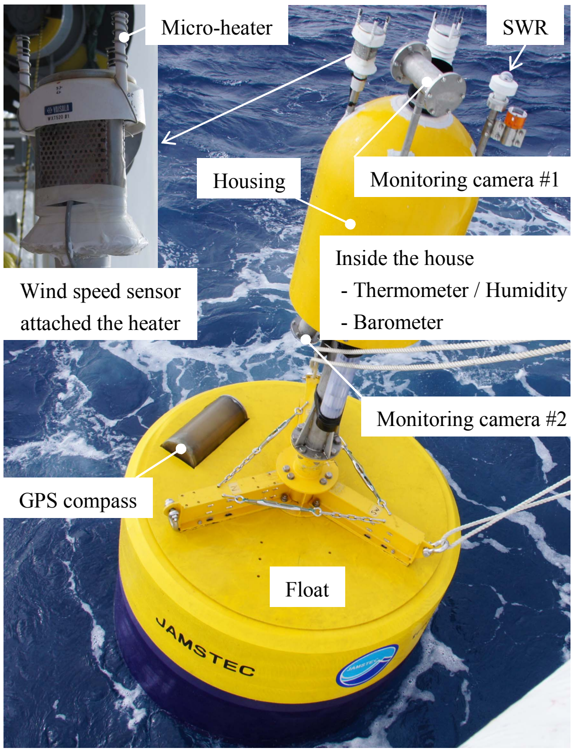

Fig.1 Right after placement of the buoy in the sea.

B. Deployment

Fig. 2 shows the buoy-hoisting operation. We loaded the Southern Ocean buoy system onto the research training vessel "Umitaka-maru" managed by Tokyo University of Marine Science and Technology in early November 2011 in Tokyo Bay and headed to the Southern Ocean then reached at the deployment position on 17 January 2012. We deployed it at 59.99°S 139.99°E in an environment of 0 °C air temperature, 4.4 m/s wind speed, and 2.3 m wave height. We chose the deployment date for calm sea conditions for the Southern Ocean because we had to handle some heavy materials such as the float (0.85 ton) and the anchor (3.3 ton).

We deployed the buoy system smoothly. However, after we let all the steady brace ropes go, the buoy drifted toward the vessel and overtook it because the slowly moving vessel. One wind speed sensor that was not equipped with a heater was hit by the vessel and was broken.

III. RECOVERY OF THE SOUTHERN OCEAN BOUY

After 11 months, on 18 December 2012, we headed to the deployment position in the Southern Ocean by the research vessel “Mirai”, which belongs to JAMSTEC. We succeeded in recovering the mooring gear that we had deployed. The sea conditions were 2 °C air temperature, 4.4 m/s wind speed, and 3 m wave height.

Fig.2 Picking up the float on UMITAKA.

Fig.3 Winching up the float for recovery by “Mirai”.

A. Recovery operation

Fig. 3 shows winching up of the float during recovery and a small working boat heading to the float. We first launched a small working boat to the float from "Mirai" and attached the drawing rope to the float. It was the most important and dangerous operation during recovery. The sea conditions in the Southern Ocean are usually rough seas, For that reason, we chose clam sea conditions to launch our small working boat. We picked up the drawing rope knotted on the float and winched up the float. We recovered all mooring gear safely.

B. Data acquisition rate

Fig. 4 shows the acquisition data rates of all sensors attached to the Southern Ocean buoy system. Fig. 4(a) shows the data rate of meteorological sensors on the float, Fig. 4(b) shows the engineering sensor data rate. Fig. 4(c) shows underwater sensor data rate. We were able to acquire almost all data considering that the sea conditions were rough and this surface mooring was the first trial in the Southern Ocean, which is an extremely high latitude: 60 °S

The humidity / temperature sensor and wind speed sensor attached a micro-heater to prevent form icing (Fig.4(a)) and a tension sensor (Fig.4(b)) on the float, which did not work on 13th February at the same time. Around that date, extremely severe conditions prevailed, as inferred from the values of meteorological sensors. The wind speed was greater than about 16 m/s for 16 hr consecutively (Fig.5 ▲), temperatures were below 1 °C (Fig.5 ■) and atmospheric pressure had fallen rapidly (Fig.7). Both meteorological sensors were leaked from the sensing portions. The tension meter's signal cable was cut off at the edge of the sensing portion. Fortunately we received all periods of acceleration data. Therefore we were able to investigate what happened to the float on that day, as described in the next chapter

Regarding underwater sensors, for CTD at 50 m and CT at 75 m, they stopped gathering data for 3 and 8 months. We are asking a sensor manufacture to investigate why they stopped sampling data. Furthermore, the CTD at 200 m and the magnetic compass at 4,400 m, both developed by JAMSTEC, ran out of battery power. We had failed to estimate the battery capacity correctly when we deployed them in low-temperature conditions. The batteries drained faster than we expected at low temperature.

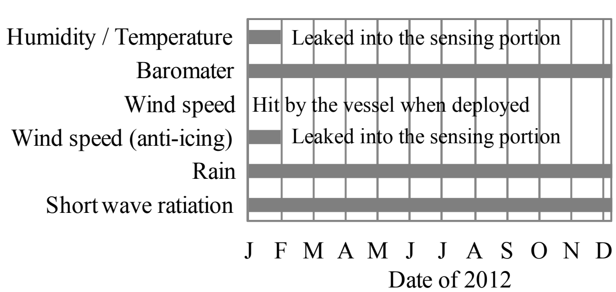

Fig.4 (a) Data acquisition rate of meteorological sensors.

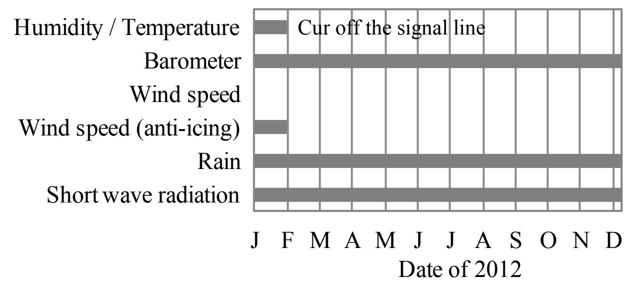

Fig.4 (b) Data acquisition rate of engineering sensors.

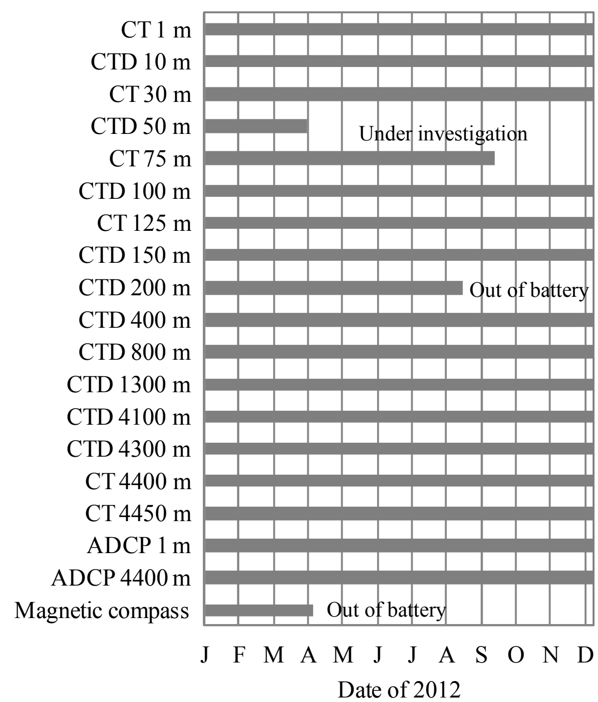

Fig.4 (c) Data Acquisition rate of underwater sensors.

Fig.4 Data acquisition rate.

IV. DATA ANALYSIS

Almost all sensors acquired data for the whole period. This chapter presents a summary of the date and provides some highlight data. Some sensors stopped sampling data. Therefore we examined why they stopped functioning by analyzing the data and by estimating the reasons for failure.

A. Highlight data

1) Wind speed and Temperature / Humidity.

Fig. 5 shows wind speed and temperature / humidity value variations that occurred when they measured correct data. The sensors, including the tension sensor, were able to take measurements until February 13. In particular, the temperature / humidity sensor broke, although it had been set in the housing to protect it from ice spray and icing. The measuring stop date was subjected to maximum wind speed throughout the monitoring period. The temperature fell rapidly to 1 °C. Apparently, the sea conditions on that date were extremely rough. Fig. 6 presents photographs of the monitoring camera, which took photographs every 1 hr, for the wind speed sensor on February 13. We attached two monitoring cameras taking photographs every 1 hr on the float (Fig.1). One of the two was set outside the housing on the top of the sensor pole, which stood on the center of the float, to monitor the icing circumstances of the wind speed sensor. The other was set in the middle of the sensor pole to monitor the icing situation on the float deck. From the background of the photographs, sea levels were leaning over: sea conditions were extremely rough.

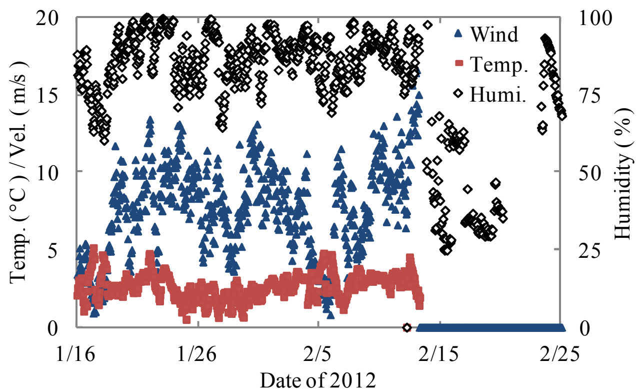

Fig.5 Wind speed and Temperature / humidity variation.

Fig.6 Wind speed sensor and sea conditions on 2/13.

2) Barometer

Fig. 7 portrays barometer variations for the entire period of 11 months. The barometer was attached in the housing and succeeded in sampling for the whole period. At 14:50 on July 18, it indicated 932 hPa, which is the minimum value for whole period. A monitoring camera photograph is portrayed in Fig. 7 on July 18. It was raining and stormy on July 18, as inferred from the photograph. Therefore the barometer data were appropriate.

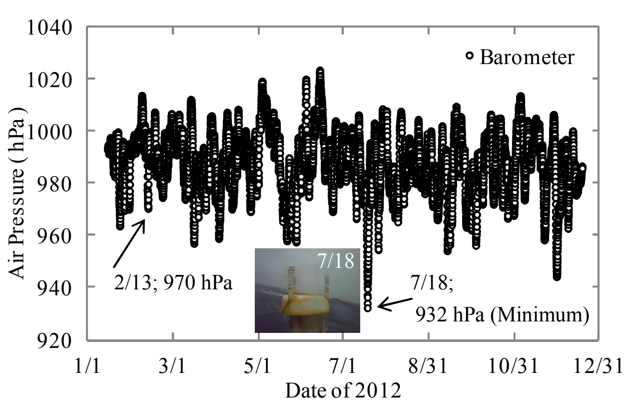

Fig.7 Barometer variation for 11 months.

3) Under-water temperature

Fig. 8 shows under-water temperatures at 4,400 m depth variation for all 11 months. It was able to obtain data during the entire period. Data from January to early July for 6 months were apparently increasing, and at the end of July they fell and apparently increased until the end of December again. Other deep-water temperatures showed the same tendency and showed appropriate data.

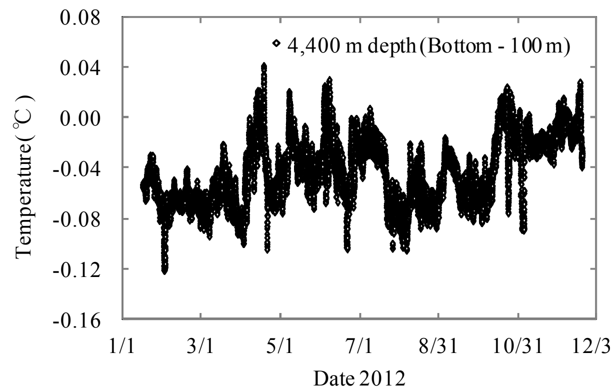

Fig. 8 Under-water temperature at 4,400 m variation for 11 months.

4) Tension

Fig. 9 shows tension meter variation at 6:00 on February 13. It samples at 10 Hz for 4 min every 3 hr. The average value is 0.53 ton·f. The maximum value is 0.82 ton·f. The weight of underwater mooring gear is about 0.5 ton·f. Therefore the sampling tension data are apparently appropriate. Furthermore, the breaking load of the polypropylene rope, one of the weakest cables in mooring components, is 6 ton·f. It is more than seven times as strong as the maximum tension value indicated for the Southern Ocean. The mooring line strength is sufficient to moor the buoy system for a year despite the rough sea conditions in the Southern Ocean.

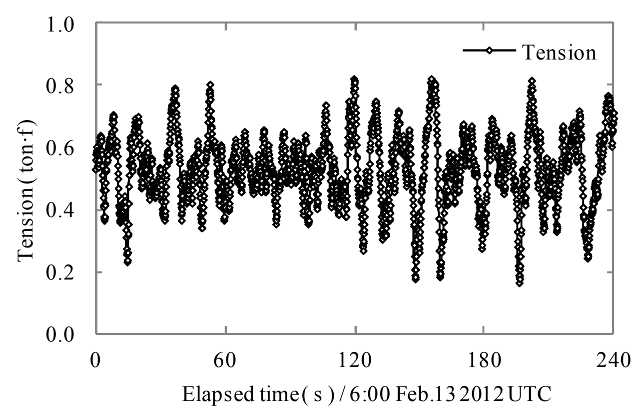

Fig.9 Tension meter variation.

5) Acceleration

Fig. 10 shows an accelerometer in vertical direction variation at 6:00 on February 13. It samples at 10 Hz for 4 min every 3 hr as well as a tension meter. The accelerometer shows a value of -1 G in a static position. The average value is

-1.01 G. Therefore, it can measure appropriately. Furthermore plot data on Fig.10 are calculated as a raw data value minus the average value to be 0 in a static position. Then the maximum upward value is 0.51 G. The downward value is 0.46 G. As might be inferred from Fig. 10 the float was forced by about 0.5 G at maximum.

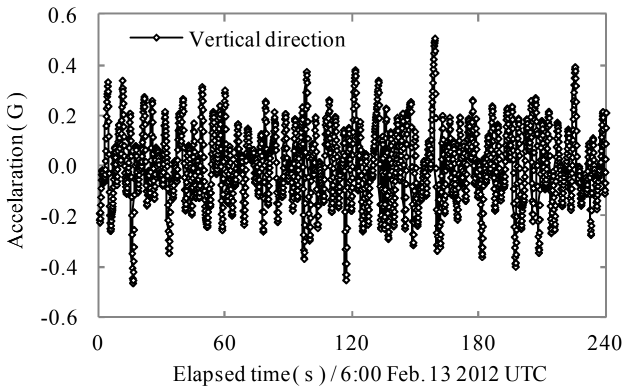

Fig.10 Accelerometer variation.

6) Icing photographs

Fig. 11 presents photographs of monitoring cameras in June to confirm anti-icing operations of the micro-heater. The micro-heater was turned on if the air temperature dropped below -0.5 °C. The temperature sensor was damaged on February 13, but it continued to record incorrect values. From April 24, it continued indicating temperatures below -0.5 °C. Therefore the micro-heater was kept turned on from April 24. The heater current that we measured rose from April 24 to June 30. The battery consumption reached about 80%. As shown in Fig. 11(a), showing data for 2:00 on June, no icing occurred on the transducer that measures wind speed, despite showing some icing on the top of wind speed sensor, which measured the rain intensity, or its body. In addition, as shown in Figs. 11(b) and 11(c), they were taken at the same time of 1:00 on June 27. The wind speed sensor transducers were not covered with ice but the GPS on the deck was covered with much ice, which implies that the heater functioned in the Southern Ocean even at temperatures below -0.5 °C. It was able to prevent icing on the wind speed sensor transducer.

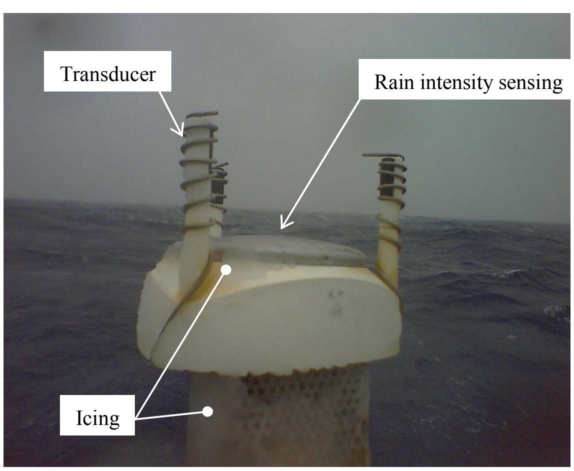

Fig.11 (a) Monitoring camera to heating point at 2:00 on 6/5.

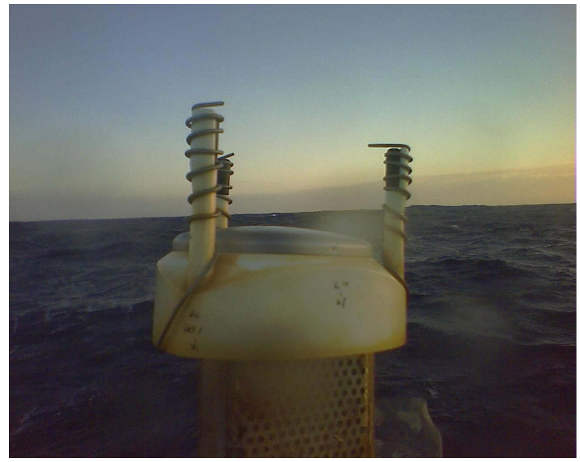

Fig. 11 (b) Monitoring camera to heating point at 1:00 on 6/27.

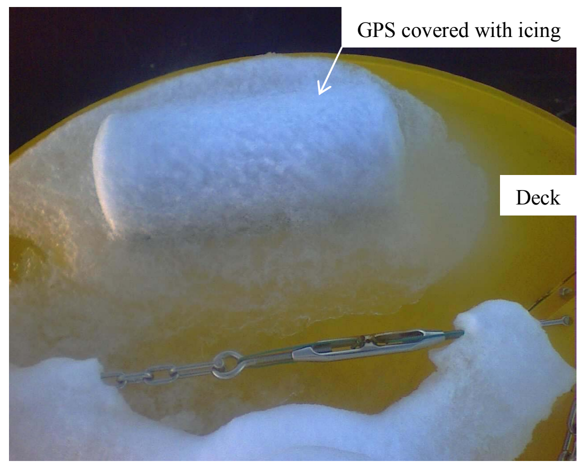

Fig.11 (c) Monitoring camera to deck at 1:00 on 6/27.

Fig.11 Monitoring camera photographs.

B. *Investigation of data deficit*

The temperature / humidity sensor, the wind speed sensor ,and the tension meter ceased functioning on the same day: February 13. Regarding the temperature / humidity and wind speed sensor, both sensing components were affected by seawater leak. Furthermore the signal line of the tension meter underwater was cut off because of extremely rough sea conditions. Fig. 12 presents the photographs of the temperature / humidity without its louver. In addition Fig. 12(b) shows the circuit board, with corrosion and obvious leakage seawater. We had covered a joint between a circuit board and a sensing component with sealant to conduct m-Triton buoy operations. In early m-Triton operations, the temperature / humidity sensor joints often leaked seawater. The joints were covered with sealant to stop leakage. In m-Triton operation, where they are moored in tropical calm oceans, the components work well. However, in the Southern Ocean, we found that the sealant was insufficient to prevent leakage.

We specifically examined February 13 data and then analyzed the accelerometer (AMU1802; Sumitomo Precision products Co. Ltd) and tension meter (LT-50KNG796M1; Unipulse corporation) data in detail. Both instruments sample at 10 Hz for 4 min every 3 hr. First we calculated the vertical displacement of the float calculated from double integration of acceleration (Fig. 13). Regarding the accelerometer, if it was moving at the start of measurement, it would not be able to measure correctly without initial errors. The quantitative displacement data were therefore not correct to be integrated the acceleration value involving the initial errors. However, focusing on each wavelength, it can be estimated that the maximum wave height would be 10 m and that the wave period would be 10-20 s. However, the wave-height from satellite data[9], which are averages for five days, are shown as 6.315 m. They can be close, between 10 m from the acceleration data, which are sampled at 10 Hz and 6.315 m from satellite data which are for 5 day averages.

Next we analyzed acceleration and tension data in Fourier transform (Fig. 14). To view the tension data, a frequency range of 0.06-0.11 Hz frequency is outstanding. Other ranges are weak. The strong range, which shows wave oscillation, is converted to a wave period of 9-17 s. These values are close to the value calculated from acceleration. In addition, regarding the acceleration data, they have two strong frequency ranges. One is the same range calculated from tension data. The other range is 0.33-0.51 Hz. The accelerometer measured the other frequency range as more sensitive to measure than the tension meter. The later frequency range, 0.33-0.51 Hz is apparently a natural oscillation of the m-Triton floats. We observed the value from former sea trials. Furthermore, the correlation coefficient between tension data and acceleration data is 0.78. The correlation between tension data and acceleration data was high. The FFT of tension and acceleration data results indicates that wavelength on February 13 is between 10 and 20 s, which implies that the measured data are appropriate. Furthermore, on February 13, extremely rough sea conditions prevailed, with maximum wave height of 10m against the float height of 2 m. The float was very likely hit by plenty of sea spray.

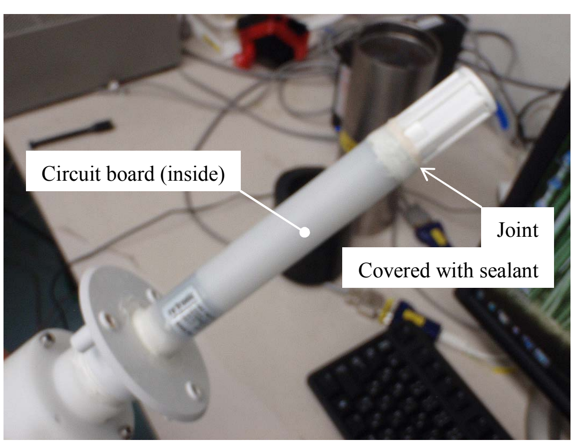

Fig.12 (a) Sensing portion of the temperature / humidity sensor.

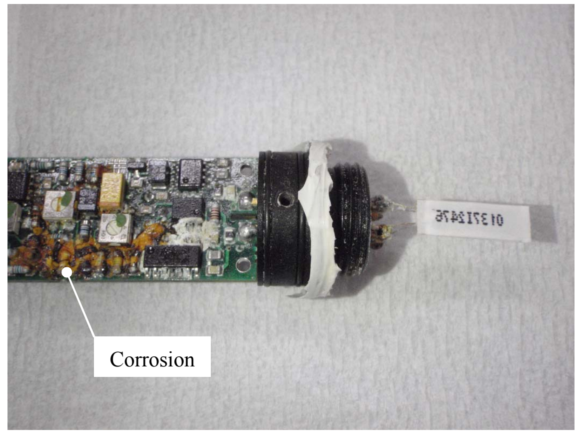

Fig. 12(b) Circuit board of the temperature / humidity sensor.

Fig. 12 Temperature / humidity sensor without its louver.

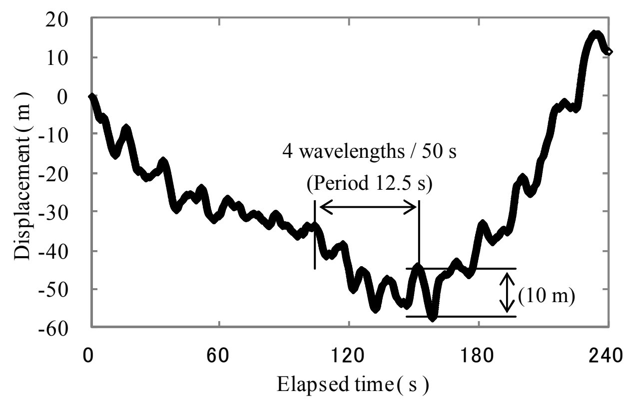

Fig. 13 Vertical displacement of the float calculated from the accelerometer at 6:00 on 2/13.

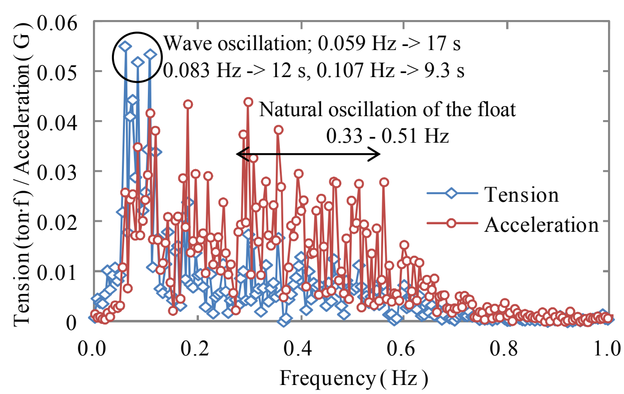

Fig. 14 Comparison FFT of tension with that of acceleration at 6:00 on 2/13.

V. Summary and Future plans

The Southern Ocean buoy mooring described here marks the world's first successful mooring of a surface observation buoy in the Southern Ocean near 60°S, a region characterized by heavy weather and low temperatures. Collection of meteorological and oceanographic data by this buoy system is still in progress. With this integration of technology previously developed at our institution and in the present Southern Ocean mooring, it will be possible to moor observation buoys at nearly any point in the world's oceans and to manage their operation, data management, and recovery.

We are continuing to analyze data gathered from the Southern Ocean buoy system. Data from the sea trail will be compared with data from calculation by some static and dynamic analysis programs. Furthermore, the results will be applied to modification of the system design wherever necessary.

When the development of this Southern Ocean surface observation buoy is completed, it will enable the performance of moored buoy observations in all except icy sea regions at latitudes higher than the 60°S latitude assessed in the present study. Follow-on development will also include observation buoy systems for icy sea regions, to meet the needs expressed by many scientists for elucidation of the influence of icy seas on ocean currents, which are closely related to changes in global climate.

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