Data Communication Status of the ARGO Floats

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ABSTRACT

We investigate the data communication status of the ARGO floats deployed until February 2001 in the seas adjacent to Japan. The mean reception rate of the data via the ARGOS system, which calculated from the periods while satellite flies overhead of the float, is 52%. The mean error rate of the transferred data, which detected by the CRC code in the data, is 21%. These rates varied according to the float position and the periods during the float stayed at the sea surface. East of Japan (35 N-40 N, 140 E-145 E) was the worst 5 degrees-grid area in communication status, where the reception rate is 7% lower than the average and 3% higher than the average. The worst 6-hours period is 12:00-18:00 in JST, when the reception rate is 9% lower than the average and the error rate is 4% higher than the average. The communication status seemed to be affected by interferences of the radio were around Japan. The second-generation ARGOS instruments have about 10% higher reception rate than the first-generation ones, but no difference found in the error rate. Considering the orbits of the ARGOS satellites, most effective periods for data communication from the ARGOS floats in the seas adjacent to the Japan is 00:00-08:00 in JST.

1. Introduction

The ARGO project is an international project launched in 2000, in which nearly 3,000 profiling floats of the same type as the ALACE (Autonomous Lagrangian Circulation Explorer) floats (Davis et al. 1992) will be deployed in the world oceans. The floats are equipped with temperature and salinity (conductivity) sensors, which will provide approximately 100,000 vertical profiles annually of water temperature, salinity, and current velocity for the areas in which the floats are deployed (Mizuno, 2000).

Currently, the ARGOS system (CLS/Service Argos Inc., 1996) is used to transmit data measured by the profiling floats. Due to technical restrictions on this communication system, there is a limit to the amount of data that can be transmitted at once. Thus, data is divided into blocks before being sent from the floats. For the reception of complete sets of observation data, all of these data blocks must be received without error. To ensure that the whole data is transmitted without fail, the profiling floats remain on the sea surface for 8-21 hours.

To guarantee successful data reception, we must analyze current communication status and apply this analysis to future float settings. Furthermore, since nearly half of float's battery budget is consumed for data transmission, it would be desirable to reduce such power consumption by shortening the amount of time the float stays on the sea surface for data transmission. It may extend the operational life of the float.

Meanwhile, one of the main problems concerning the data obtained by these profiling floats is the accuracy of salinity measurements in long-term observations. Salinity is a function of pressure, temperature and conductivity. The conductivity sensors are affected by subtle physical deformations or fouling on the sensor surface, and are thus susceptible to a short-term reduction in accuracy relative to the pressure and temperature sensor. In the past, large drifts have been observed in the sensitivity of conductivity sensors, believed to be caused by marine growth (see, for example, Freeland, 1997). As a result, the float sensors are now coated with marine-growth inhibitors. However, it is expected that shortening the time the float resides at the surface where marine growth is most likely to occur will contribute significantly to the long-term stability of conductivity sensors.

In this paper, we will analyze the current communication status of the profiling floats (hereafter referred to as the “ARGO floats”) deployed by the Ocean Observation and Research Department of the Japan Marine Science and Technology Center and the Frontier Observational

Research System for Global Change (JAMSTEC /FORSGC). We will also discuss the setting of an efficient communication period to the ARGO floats to be deployed in the future.

2. Communication Status of ARGO Floats

Seventeen ARGO floats deployed before February 2001 were used in the analysis (Table 1). Using the ARGOS system for data transmission, the maximum message size that can be transmitted at once is 32 bytes. Since the data volume of a single observation by the ARGO float is approximately 400 bytes, the data is divided into 12-14 message blocks and sent repeatedly, in message-number order. A CRC code is included to each block so that it can be compared with the CRC code calculated from the received data, to check for errors in transmission. The transmitted data is sent to ARGOS ground station via ARGOS satellites that pass over the float. It is then delivered to users--via e-mail, for example.

Each ARGOS satellite flies a sun-synchronous polar orbit at an altitude of 850 km. It takes about 102 minutes to complete one revolution around the Earth and shift its orbit 25 degrees westerly (2800 km at the Equator) per revolution. The satellite passes through the visible area of a given ARGOS transmitter at almost the same local time each day. The satellite can communicate over an area with a ground radius of approximately 5,000 km. The overlap in the area covered by the ARGOS transmitters increases at higher latitudes. Two satellites fly through the visible area of an ARGOS transmitter 28 times at the polar region and 6-7

Table 1. Summary of the ARGO floats deployed before February 2001 by JAMSTEC/FORSGC.
WMO ID: The number specific to a float assigned by the World Meteorological Organization. ARGOS ID: The identification number of the Platform Terminal Transmitter (PTT) used by the ARGOS system. All floats are APEX-type floats manufactured by the Webb Research Corporation. No data has been transmitted by floats WMO ID 29034 and 29035 since Jan. 28, 2001, nor by 29042 since Feb. 25, 2001, nor by 29047 since June 6, 2001. Floats WMO ID 29032 and 29033 could not resurface due to a lack of float buoyancy in low-density surface seawater during the period of Aug. 9 – Oct. 18, 2000, and Aug. 9 – Nov. 4, 2000, respectively. These floats are believed to have drifted near the surface during this period, and the ascent/descent cycle of the floats was disrupted. The surface cycle of the floats since autumn 2000 is shown in parentheses.

WMO ID	ARGOS ID	CTD sensor	Parking Depth (db)	Mean Surface Residing Time (hours)	Surface Residing Period (JST)	Obser-vation cycle (days)	Repeti-tion rate (sec.)	Date of deployment (JST)
29032	28935	SBE	1500	19	17h~12h (18h~13h)	28	90	2000/03/22
29033	28936	SBE	1500	19	17h~12h (10h~05h)	14	90	2000/03/22
29034	28938	SBE	2000	21	22h~19h	10	90	2000/10/21
29035	28940	FSI	2000	21	22h~19h	10	90	2000/10/21
29042	06496	SBE	2000	8	02h~10h	10	44	2001/02/16
29043	06495	SBE	2000	8	06h~14h	10	44	2001/02/16
29044	06498	SBE	2000	8	10h~18h	10	44	2001/02/16
29045	06497	SBE	2000	8	12h~20h	10	44	2001/02/16
29046	06500	SBE	2000	8	16h~24h	10	44	2001/02/16
29047	06499	SBE	2000	8	18h~02h	10	44	2001/02/16
29048	06503	SBE	2000	8	21h~05h	10	44	2001/02/16
29049	06502	SBE	2000	8	00h~08h	10	44	2001/02/17
29050	06504	SBE	2000	8	04h~12h	10	44	2001/02/17
29051	06505	SBE	2000	8	10h~18h	10	44	2001/02/17
29052	06506	SBE	2000	8	14h~22h	10	44	2001/02/17
29053	06507	SBE	2000	8	21h~05h	10	44	2001/02/17
29054	06510	SBE	2000	8	01h~09h	10	44	2001/02/18

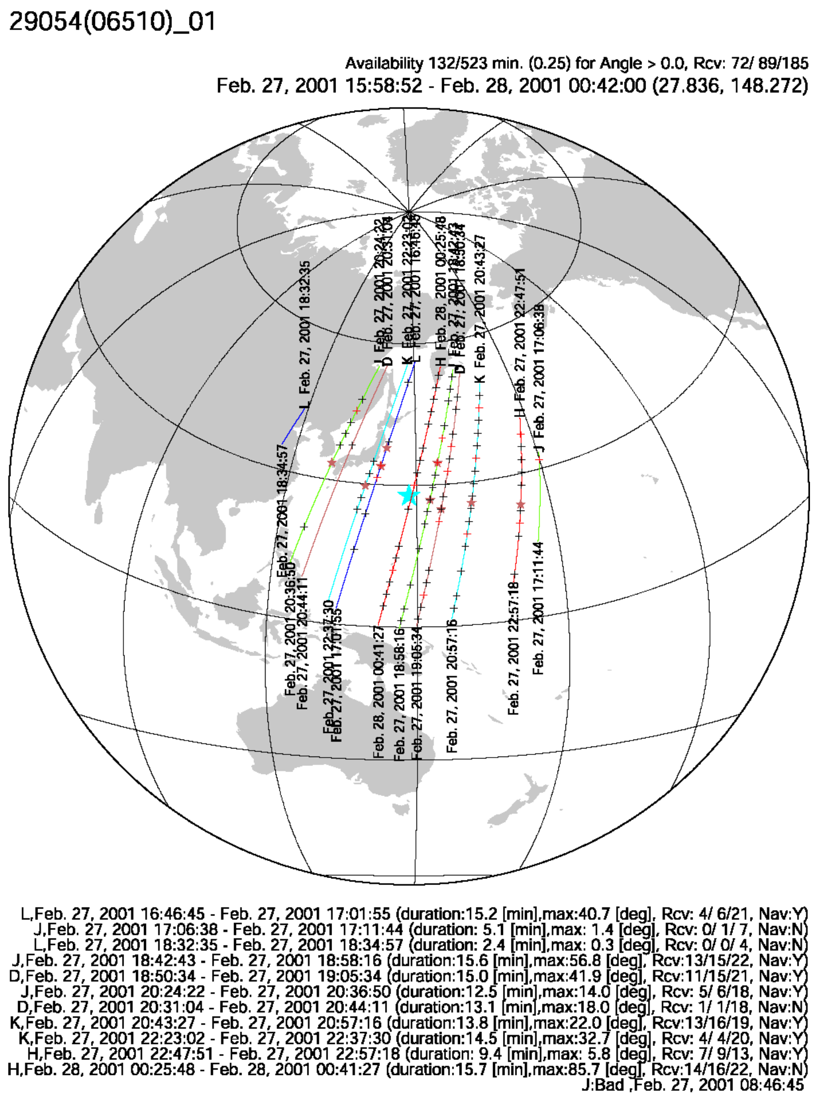

Figure 1. Example of ARGOS satellite tracks which possible to communicate with ARGO float. Light blue star indicates the ARGO float position. Red stars show the satellite positions when float position fixed. Black and red crosses on the satellite track show the ARGOS satellite positions when satellite received data from the float without error and with error, respectively.

times at the equatorial region per day. The average duration of float/satellite visibility ("visible time") is 10 minutes, with a maximum duration of 15 minutes (CLS/Service Argos, Inc., 1996). The satellite's orbit can be calculated from Kepler's Law when the orbital elements are given. We use the orbital elements provided by North American Air Defense Command (NORAD) and use free software PREDICT which is provided by John A. Magliacane (available at http://www.qsl.net/kd2bd/predict.html) to calculate the paths of five satellites, to find all paths with an elevation greater than 0° when seen from a float during the float's stay at the sea surface. This information was used in turn to calculate the visible time as shown in Fig.1. By dividing the visible time by the transmission repetition periods, we may obtain the maximum number of data that a float is able to transmit to a satellite (maximum possible reception). Also, from the data actually received, the number of received data (total reception) and the number of data received without CRC error (error-free reception) may be obtained. Hereafter, the ratio of total reception to maximum possible reception is called the reception rate, and the ratio of reception with error to total reception is called the error rate. The current communication status was thus subject to statistical analysis, revealing an average reception rate of 52% and an error rate of 21% for 17 ARGO floats resurfacing a total of 193 times before June 18, 2001. In the following section, we will present the results of analysis of communication status according to region and time period.

2.1. Communication Status by Region

To analyze differences in communication status according to region, we divided the region between 30 N-45 N and 135 E-145 E into grids of 5-degrees x 5-degrees and calculated the reception rates and error rates for each grid (Fig. 2). The region nearest the Japan had the worst reception rate, 7% lower below average, with an error rate 3% above average. The difference in reception and error rates is more significant in the E-W direction than in the N-S direction. The low reception rate and high error rate in the regions neighboring Japan may be attributable to interference from radio waves from land. Presently, there are five satellites in the ARGOS system: the NOAA-D, H, J, K, and L. They can be classified into two groups, according to their on-board communication systems. First-generation satellites are NOAA-D, H, and J, hereafter referred to as ARGOS I and second-generation satellites are NOAA-K and L, hereafter referred to as ARGOS II with improved reception sensitivity (CLS/Service Argos, Inc., 1999 as listed in Table 2). There was no obvious difference in the error rates between the two groups, but the reception rate was higher for ARGOS II in all regions by 5 - 15%.

2.2. Communication Status by Time Period

To understand the difference in communication status according to time period, the reception and error rates were calculated for 6-hour periods between 0:00-6:00, 6:00-12:00, 12:00-18:00, and 18:00-24:00, JST (9 hours ahead of UTC. Since local time of resurfacing point almost equals JST, JST is used in this paper as shown in Fig. 3). In the 0:00-6:00 period, the reception rate was 4%

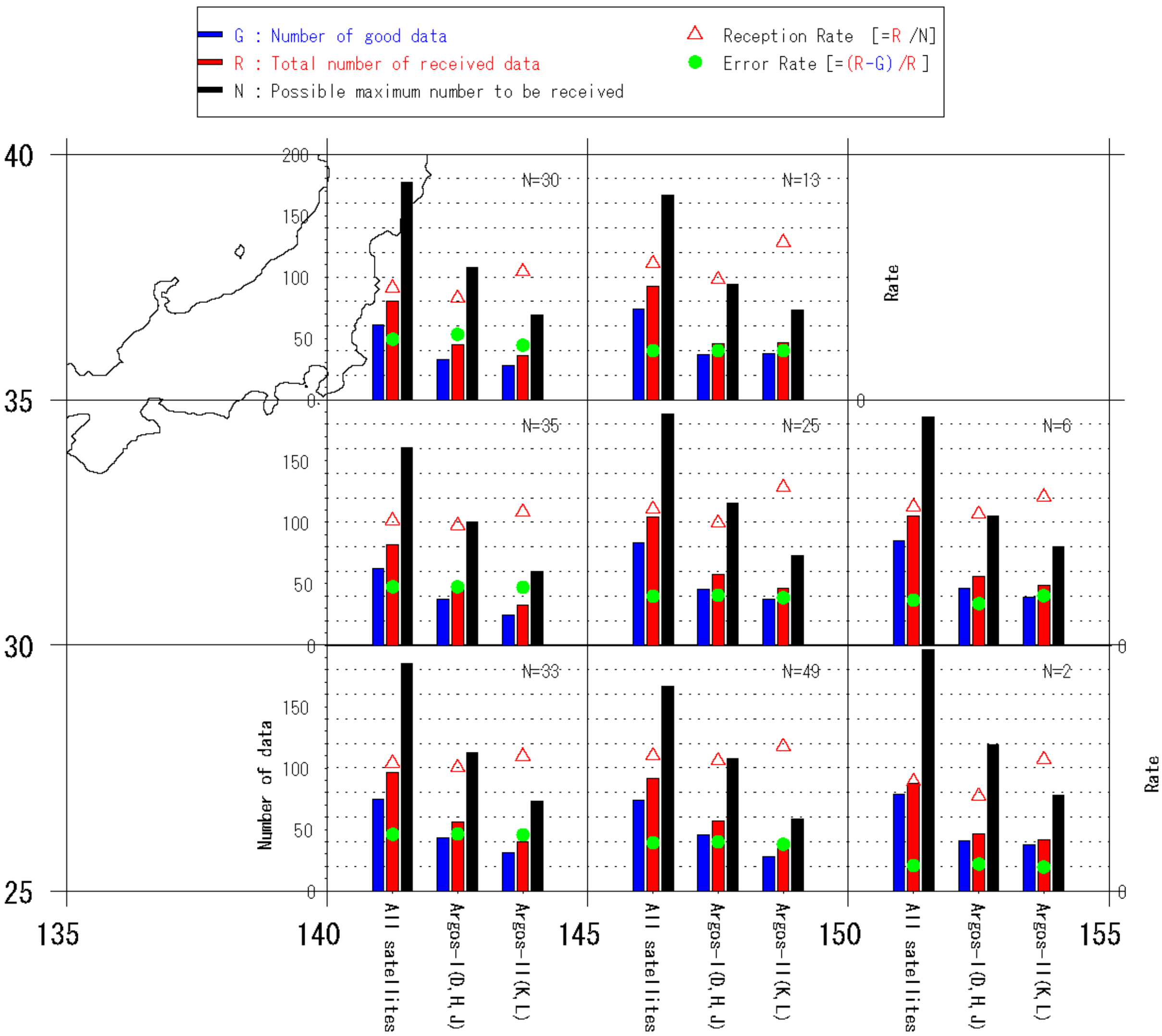

Figure 2. Status of the data communication via ARGOS system in each 5 degrees-grid.

Table 2. Characteristics of the ARGOS instruments on the NOAA satellites.

Satellite Name	Band-width (KHz)	Receiver (dBm)	Proc.Units	Link Speed (bits/sec)
NOAA-D	24	-128~-108	4	720
NOAA-H	24	-128~-108	4	960
NOAA-J	24	-128~-108	4	1200
NOAA-K	80	-131~-108	8	2560
NOAA-L	80	-131~-108	8	2560

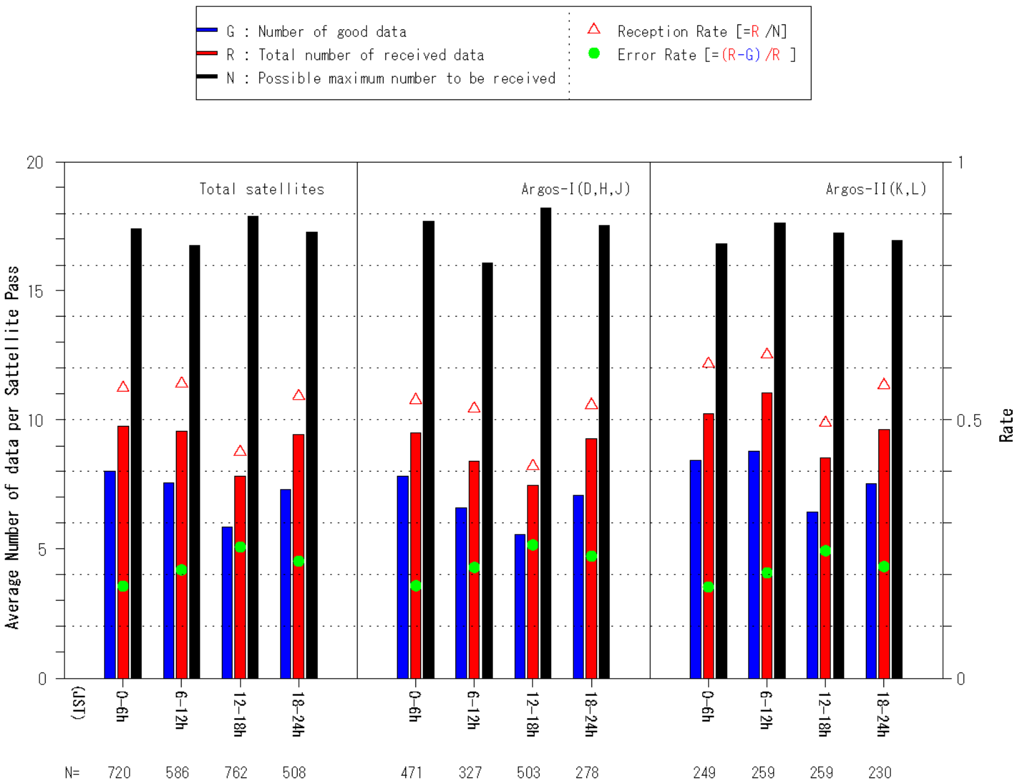

Figure 3. Status of the data communication via ARGOS system in each 6 hours period.

higher than average, with an error rate 4% lower than average. On the other hand, the 12:00-18:00 period showed a reception rate 9% lower than average and an error rate 4% higher than average. The reception rates in the 6:00-12:00 and the 18:00-24:00 periods were approximately the same as those of the 0:00-6:00 period, but the error rates were 4% higher. It may reflect interference from radio waves transmitted around Japan. There was no apparent difference between the two groups of satellites in terms of reception rates and error rates according to time period.

2.3. Communication Status by Season

We investigated differences in communication status according to season in reception and error rates every 3 months. Communication status was examined for the WMO ID 29032 and 29033 ARGO floats, which have each been in operation for more than one (Fig. 4). Although reception rate for the period from April – June 2000 showed more than 10% higher than that of other periods, there are no apparent differences in reception rates after July 2000. As the changes in error rates were small throughout the studied period, it was thus concluded that there is almost no variation in communication status according to season.

2.4. Sea Conditions and Communication Status

An ARGO float must resurface to communicate with a satellite. When wave height is high, the float's attitude will be unstable. It may result in inferior communication status. We investigate the relationship between wave height that is calculated by the Costal wave height model operated by Japan Meteorological Agency and reception and error rates in the regions where floats resurfaced (Fig. 5). The coefficient of correlation between wave height and reception rate was 0.02, and that between wave height and error rate was 0.29. It was thus found that reception rate is not affected by wave height, but that error rate increases with wave height. Davis et al. (1992) studied the relationship between wind velocity and number of position fixed and the relationship between wind velocity and total reception using surface floats of the same shape as the ALACE floats, reporting no observed correlation between them. This result does not contradict our results.

2.5. Receive Level of the Satellite and Communication Status

We studied the relationship between the received signal level of ARGO float at satellites and the reception and error rates for the period from March 17, 2001 to June 7, 2001, the period for which satellite receive level data is available. Figure 6 shows the error rates, reception rates, mean receive levels, and standard deviations for each float, the mean receive level for all floats, and the time period during which the floats were at the sea surface. The receive level of float 29047 was higher than the other floats by approximately 3 dBm, but there was no significant difference between its reception and error rates relative to the other floats. On the other hand, float 29046 had a receive level lower than the other floats by 1-2 dBm, with the lowest reception rate and the highest error rate. In particular, the increased error rate

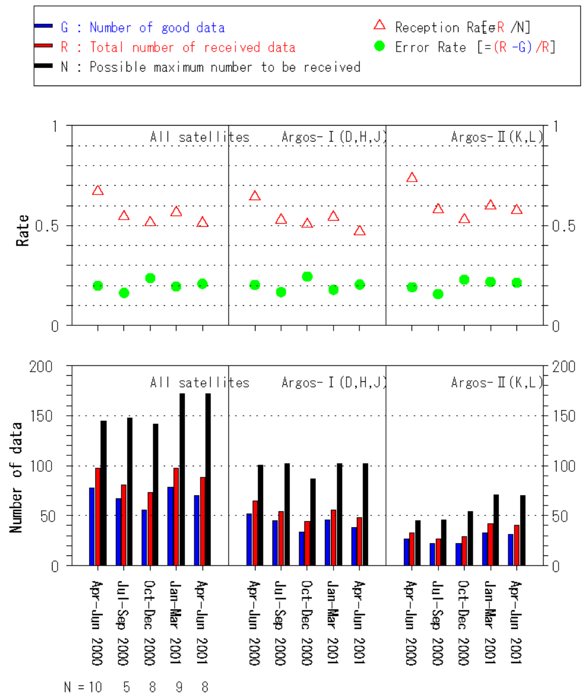

Figure 4. Status of the data communication every 3 months for the float 29032 and 29033 from April 2000 to June 2001. Data communication status for 3-month periods for floats 29032 and 29033. However, since float 29032 failed to resurface due to lack of buoyancy between Aug. 9 and Oct. 18, 2000, as did float 29033 between Aug. 9 and Nov. 4, 2000, there is no data for these periods. NOAA-L was launched in the autumn of 2000 and was available for use starting in October. N represents the number of times a float resurfaced.

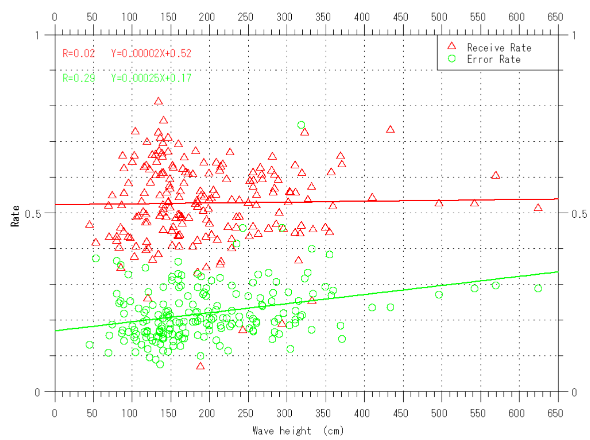

Figure 5. The reception rate (red triangle) and the error rate (green circle) vs. wave height where floats stayed.

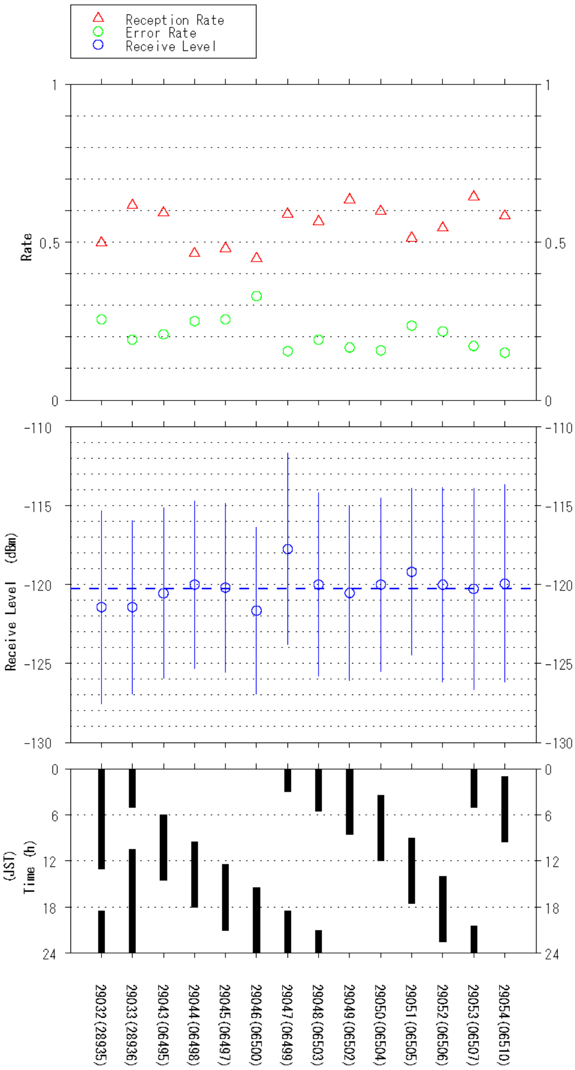

Figure 6. Receive level of the ARGO float and communication status. From top to bottom, communication status (red triangles: reception rates; green circles: error rates), receive level (mean: circle, and its standard deviations, and the mean for all floats), and the time period during which the float remained on the sea surface.

relative to other floats was more significant than the decreased reception rate. The other floats each have characteristic reception rates and error rates, but there seems to be no correlation to receive level. The drifting at sea surface time period seems to have a greater effect on reception and error rates. In Section 2.2, it was shown that the 12:00-18:00 period displayed the highest error rate and the lowest reception rate, and that the 0:00-6:00 period showed the lowest error rate and the highest reception rate. Since the surface periods for floats 29042 - 29054 are about 8 hours, resurfacing during the 12:00-18:00 period results in high error rates and low reception rates and resurfacing during the 0:00-6:00 period results in low error rates and high reception rate.

Figures 7 and 8 show the error rates, reception rates, average number of received data, and number to be received as a function of receive level for ARGOS I and ARGOS II, respectively. From Fig. 7 and 8, it can be seen that the maximum possible number of received data is large when the receive level is high. It implies that the receive level is highest when a satellite passes just above a float. There is a rapid increase in error rate and decrease in reception rate below -128 dBm. The weighted mean of the reception and error rates were calculated for receive levels below and above -128 dBm, which is the nominal reception sensitivity of ARGOS I, and are shown in the plot by dashed lines. For both ARGOS I and II, the group with receive levels below -128 dBm showed a 25% lower mean reception rate and a 17% higher mean error rate than the group with receive levels above -128 dBm. Compared to ARGOS I, ARGOS II had reception rates that were 10% higher both above and below -128 dBm, although there was no apparent difference in error rates.

No data has been received from float 29047 after its 11th resurfacing, and since it had displayed a rapid drop in power-supply voltage, it is highly likely that its batteries have run out. As stated previously, the receive level from this float was 3 dBm higher than the others. It could result from a difference in transmission power, as float 29047 had twice the transmission power of other floats. It may also be one of the reasons for the rapid drop in the power supply of the float.

3. Discussion

An analysis of the relationship between an time period and the reception rate classified in 5-derees x 5-derees regions shows that the seas neighboring Japan feature low reception rates and high error rates, especially during the 12:00-18:00 period. It may be due to interference. Based on these reception and error rates, it was found that the floats to be deployed in the seas neighboring Japan

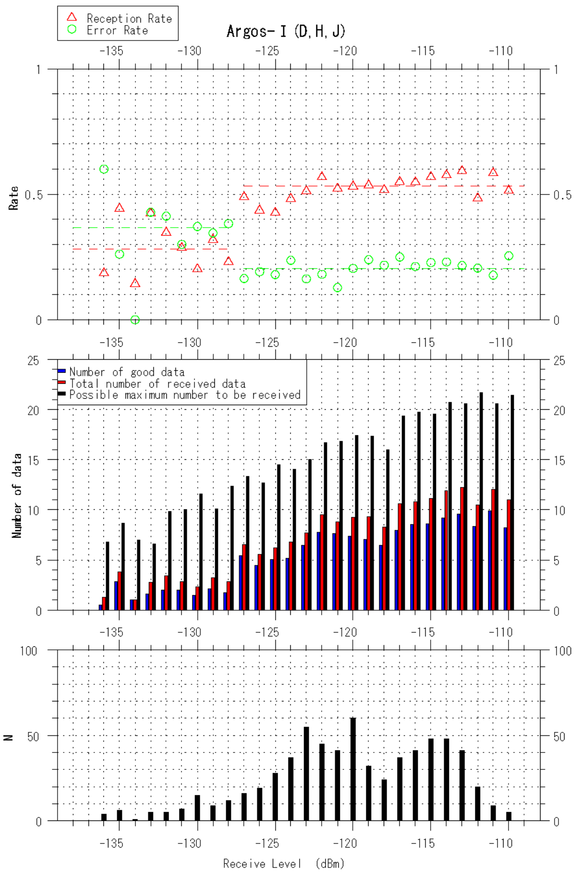

Figure 7. Communication status at each receive level (ARGOS I: D, H, and J). From top to bottom, communication status, number of received data, and number to be received as a function of receive level. The dashed line in the plot for communication status shows the weighted means of reception rates and error rates calculated for receive levels below and above -128 dBm.

should be set to resurface between 0:00 and 6:00. Since there is a 10% difference in the reception rate between ARGOS I and ARGOS II satellites, the reception rate can be improved if the float is set to resurface when an ARGOS II satellite (with higher reception sensitivity) is flying over it. Although it will not affect the error rates, the improved reception rate will enable more efficient data reception. The satellites used in the ARGOS system have sun-synchronous orbits, and Fig. 9 shows their orbits in solar time. If the floats are set to remain at the sea surface for 8 hours, as is the case for floats 29042-29054, it can be seen from Fig. 9 that a preferable surface period is between 0:00 and 8:00, providing the benefits of both an

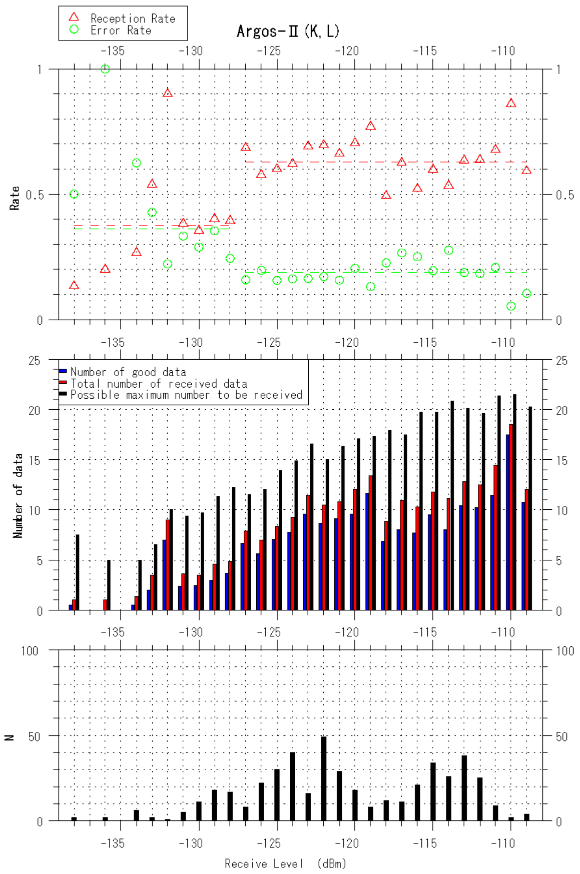

Figure 8. Same as Fig.7 except for the 2nd generation satellites (ARGOS-Ⅱ; K, L).

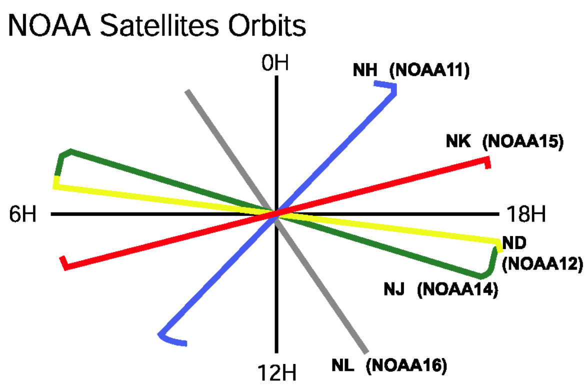

Figure 9. Orbits of NOAA POES (Polar Orbiting Environmental Satellites) used for the ARGOS system.

ARGOS II satellite with a good reception rate and the minimum interference 0:00-6:00 period. The present results indicate that there is no correlation between the seasons and the reception and error rates, and no correlation between wave height and reception rate, although the error rate increases with greater wave height.

The current surface time of a float is set to enable the reception of several cycles of message blocks, repeatedly sent by the ARGOS transmitter to ensure the reliability of data. If there are no improvements in the ARGOS system hardware functions, then in order to reduce a float's surface time, it will be necessary to determine the ideal communication settings that will minimize errors during data transmission, and also to analyze the number of received data for each of the 12-14 message blocks. It is not presently possible to evaluate the feasibility of reducing the surface time of the floats.

The mean reception rate and the error rate of ARGO floats deployed by JAMSTEC/FORSGC are 52% and 21%, respectively. The Riser at the University of Washington (UW) has deployed ALACE floats in the Japan Sea and the Atlantic Ocean, and has made information on the reception and error rates of these floats available through their website. The floats used by the UW are the same as our Webb floats. According to their results, the reception rate and error rates in the Japan Sea are 86% and 17%, respectively, and in the Atlantic, 85% and 17%, respectively, as of July 27, 2001. The reception rate for JAMSTEC/ FORSGC floats is over 30% lower than the UW's values, but it is due to a difference in the method of calculating maximum possible number of data received. Researchers at the UW use the time period of the satellite's orbit during which data was actually received as the duration of communication when calculating the maximum possible data number, while at JAMSTEC/FORSGC, all orbits with an angle of elevation greater than 0° during a float's surface period are used. Therefore, the maximum possible reception number is larger for the method taken by JAMSTEC/FORSGC compared to the UW, which results in lower reception rates. If we use the same method used by the UW to calculate maximum possible reception, then the reception rate for all JAMSTEC/FORSGC floats is 88% (Table 3), which is equivalent to the rate calculated by the UW. However, the floats operated by the UW in the Japan Sea, geographically closer to us, tend to have lower error rates than our floats. The reason for this is unclear.

Table 3. The reception rate and the error rate for the floats operated by JAMSTEC/FORSGC and University of Washington.

	JAMSTEC/ FORSGC	University of Washington	
	North West Pacific	Japan Sea	Atlantic
Reception rate (%)	52* / 88**	86**	85**
Error rate (%)	21	17	17
Number of data	193	2564	537

* Calculation method at JAMSTEC /FORSGC
** Calculation Method at University of Washington

The climate and marine observation system operated by JAMSTEC at Okinotorishima performed real-time data transmission with the ARGOS system until April 2000 (Nakano and Fujimori, 1998). Okinotorishima is a single isolated island and is not affected by interference from land. Since data transmission from Okinotorishima uses an antenna fixed on the ground, there is less likelihood of the errors than with ARGO floats. For comparison, the communication status of the system operated at Okinotorishima in April 2000 was calculated using the same method as that used for the floats. The result was a reception rate of 81% and an error rate of 8%. Furthermore, Sherman (1992) conducted a performance test of the ARGOS system at the Scripps Institution of Oceanography (SIO) and found that 9% of the total received data contained bit error at least one, and that the error was not due to simple bit loss, but rather was caused by successive noise bursts. Based on these results, the ARGOS system is thought to characteristically have an error rate slightly below 10%. On the other hand, the float used by Takatsuki et al. (2000) is more compact than ARGO floats, with an error rate reaching 20-50%. Takatsuki et al. (2000)

concluded that this high error rate was possibly due to the wave motion of the floats. The error rates of the JAMSTEC/FORSGC ARGO floats and those of the UW are around 20%. It is considered to be a result of the 10% error characteristic of the ARGOS system as well as of the factors described in Sections 2.1 and 2.2 such as interference, the height of the antenna above the sea surface, and the effect of wave motion.

4. Conclusions

The following results were obtained through analysis of the communication status of ARGO floats.

- The data-reception rate calculated from the maximum possible number of received data determined from an ARGOS satellite orbit and the number of actually received data was 52%. The error rate of the received data was 21%.

- The region nearest to Japan had an error rate 7% higher and a reception rate 3% lower than average.

- The 12:00-18:00 (JST) period showed a reception rate 4% lower and an error rate 4% higher than average. The 0:00-6:00 (JST) period showed a reception rate 9% higher and an error rate 4% lower than average.

- The mean receive level and the error and reception rates seemed to have no correlation, except at low receive levels. Compared to above -128 dBm, the reception rate fell by 25% and the error rate increased by 17% below -128 dBm. The reception rate fell by 25% and the error rate increased by 17% below -128 dBm.

- The second-generation ARGOS II communication system had a reception rate 10% higher than that of the ARGOS I. However, there was no apparent difference in the error rates. Based on these results, for the most efficient data-reception from ARGO floats deployed in the seas neighboring Japan, the float's surface period should be set from 0:00-8:00 (JST) when the NOAA-D, J, K, and L satellites will fly over the float. In the future, to determine whether the float's surface time can be shortened, it will be necessary to determine the communication settings that will minimize error during data transmission and to examine the percentage of good data for each message block.

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We used the free PREDICT software written by John A. Magliacane (http://www.qsl.net/kbd/predict.html) to calculate satellite orbits. The Office of Marine Prediction of the Japan Meteorological Agency provided the wave-height data for the analysis of wave height and communication status. Mr. Hidefumi Yatomi of Cubic-i Co., Ltd. provided the receive level data for analysis of satellite receive level and communication status, and Mr. Iwao Nakano at JAMSTEC provided the ARGOS communication data at Okinotorishima. We would like to express our gratitude to all these individuals.

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