Evidence of Diurnal Fish Migration in the Japan/East Sea

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Abstract. In 1999, 25 inverted echo sounders equipped with pressure gauges (PIES) were deployed for two years in the Ulleung basin in the Japan/East Sea. The main goal of this project, funded by the Office of Naval Research contract N00014-98-1-0246, was to study the variability of the Tsushima Current. When these instruments were recovered in 2001, a diurnal signal was present in 22 of the 23 PIES recovered. This signal was determined to have a depth range of 170 to 200 meters and a maximum depth of approximately 250 meters. The maximum depth was determined to occur between 10am and 3pm every day. This diurnal signal can be described by the daily vertical migration of fish. These fish have migration depths and ranges that correspond to those observed in the data. The also migrate at the same times of the day that the data migration period showed, lower in the water column during the day and toward the water surface at night. These and other correlations between the observed diurnal signal and fish migration will be discussed.

1. Introduction

The East Sea, also known as the Sea of Japan, is a unique body of water that demonstrates most of the physical processes that occur in larger ocean basins. The northern portion of the Japan/East Sea (JES) is ice-covered during winter months, whereas the southern portion is subtropical during most of the year. These conditions allow oceanic phenomena that generally do not take place near each other to happen simultaneously and within a few degrees of latitude and longitude. Since the JES simulates large-scale oceans so completely, scientists hope that a thorough study of this region will lead to great improvements of general physical oceanographic knowledge. (Riser 1)

Studies of this region by countries surrounding the JES have taken place for decades. Recently, with improved foreign relations, U.S scientists, with funding from the Office of Naval Research, have actively joined the exploration of the physical properties of this oceanographic region. Approximately 15 investigators are being funded to work collaboratively with Korean and Japanese researchers to study ocean circulation in the JES. The ultimate goal of these projects is to assimilate the observational data into high-resolution numerical models (Riser 34-5).

2. Background

The majority of water entering into the Japan/East Sea enters through the Tsushima Strait, also known as the Korea Strait, which is located in the southeastern region of the JES. Please refer to Figure 1. The current responsible for this dominant source of water circulation in the sea is known as the Tsushima Current. Previous observations during the 1930’s and several modeling experiments during the 1980’s show that the Tsushima Current splits into two or three branches after leaving the strait and while entering into the Ulleung Basin. One branch travels along the Japanese coast and one branch, referred to as the the East Korea Warm Current, travels along the east coast of the Korean peninsula. (Kim 13-22)

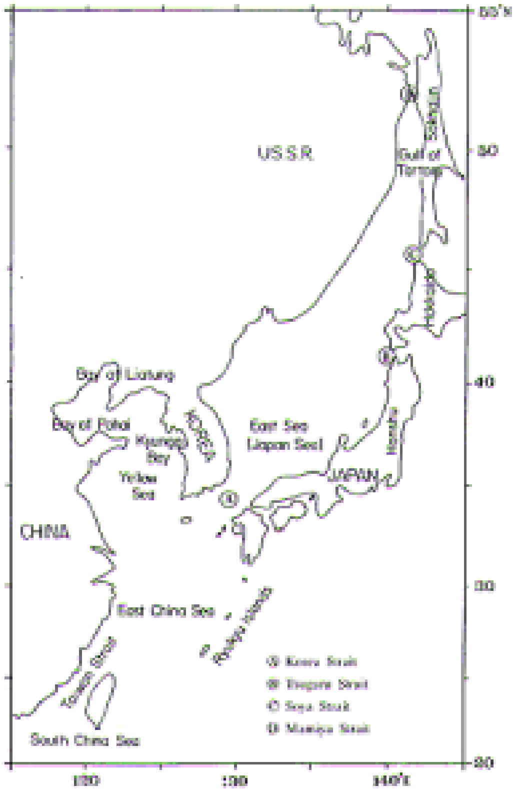

Figure 1. This is a map of the East Sea or Sea of Japan (JES). Figure found in (Kang 26).

There are two schools of thought on the third branch that may or may not exist between the first two branches. Some believe that there is indeed a third branch that appears during the summer months when the transport through the Tsushima Strait increases. Others believe that meanders or eddies of the East Korea Warm Current are mistaken to be this “third branch.” The current branch that travels along the Japanese coast is generally believed to be consistent, but many scientists believe that the East Korea Warm Current (EKWC) follows a path of much more variability.

The main objective of this project was to observe the branches of the Tsushima Current as they travel through the JES. Due to the shallow nature of the region that the Japanese coast branch of the Tsushima Current traveled through, the time-varying transport could not be measured. However, attempts were made to measure

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the time-varying transports of the EKWC and the questionable third branch. Daily maps will be produced with mesoscale resolution to show the path variability of the current. Other work will lead to a better understanding of how shallow and deep currents in this region relate when there are large-amplitude meanders, steep loop formation, and ring pinch off in the upper layers.

3. Data

During cruise HAHNAR06 on the R/V Roger Revelle (June 6-16, 1999, Pusan-Pusan), 25 inverted echo sounders with pressure gauges (PIESs) were deployed in a 5 by 5 array with 55-60 km spacing between sites. These sites are designated by yellow diamonds in Figure 2. Magenta circles designate the 18 current meter moorings located within the array. During this cruise, only 13 of the 18 current meter moorings were deployed. The current meter moorings labeled with an M preceding the site number were deployed on this cruise. Scientists at the Korean Ocean Research and Development Institute (KORDI) deployed the four current meter moorings labeled with KM. The current meter labeled with JM was deployed by Japanese scientists. Two years later on cruise COOK0901 on the R/V Melville (June 21 – July 4, 2001 Pusan-Pusan), 23 PIES were recovered and 12 current meter moorings were recovered. Two of the instruments not recovered were lost due to equipment malfunction. The third instrument never responded to attempted communication. CTD measurements were taken at each PIES site. The fishing industry is prominent in the JES, therefore this instrument is presumed to be flooded or missing due to local fishing activity. Only data collected by the PIES will be discussed in this paper, so the deployed current meter moorings will not be discussed further.

The PIES used in this observational investigation recorded travel time, pressure, and temperature measurements every hour. To measure the travel time, 24 pings were emitted from the PIES one at a time in 10-second intervals for an elapsed time of 3 minutes and 50 seconds at the beginning of each hour. There was a time lockout for each PIES, so that only pings returning to the detector after a certain time period pertaining to a certain depth would be recorded. This depth was generally set to 300 meters less than the actual depth at which the PIES was located. The pressure was averaged over the entire hour, and the temperature measurement was averaged over a one-minute interval just before the data was recorded. The PIES recorded the data at the end of each hour, just before the next travel time measurement series began.

There were three types of PIES instruments used in this investigation. Two of the types recorded the measurements on tapes and the other type utilized a solid-state memory module. Transferring the data from

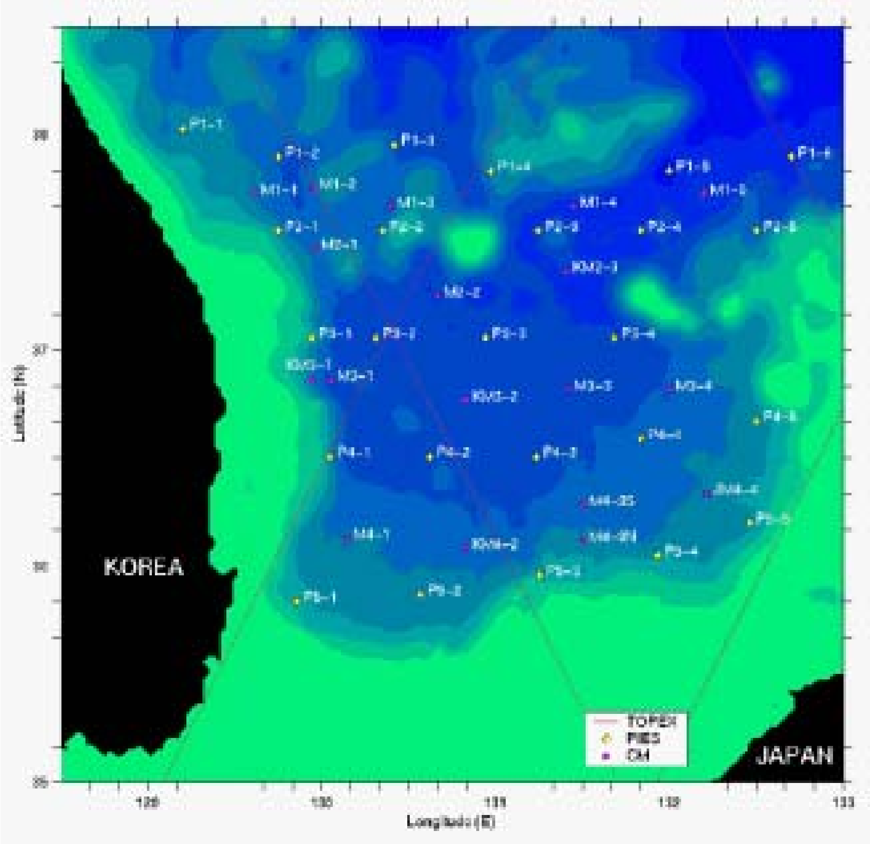

Figure 2. This is a map of all of the sites in the 5 by 5 array of instruments deployed in the Ulleung Basin of the Japan/East Sea. The yellow diamonds represent inverted echo sounders with pressure gauges (PIES) and the magenta circles represent current meter moorings (CM).

the tapes and the solid-state memory recorder took between 45 minutes to an hour. The tapes were read into computer data files using a Sea Data Tape Reader and an Asynchronous Reader Interface (ARI). The ARI interfaced between the tape reader and the computer. The ARI reads data from the tape reader until its buffer is filled. It then transfers the data one record at a time to the computer at a controlled rate. When the buffer is empty, the process is repeated until all data is read from the tape. The PIES with solid-state memory recorders contained a microprocessor. By linking the two via serial cable, the data could be transferred to the computer.

While at sea, data recovered from the PIES were examined for completeness and any obvious complications before processing began. Good travel time, pressure, and temperature records were obtained from all of the instruments with two exceptions. One instrument had no temperature records after deployment, and the travel time measurements of another instrument stopped at about two and a half months into the two-year period.

4. Results

Besides the signal of interest, there was a common phenomenon easily observed in most of the records. This was a diurnal signal that was present in the tau records. Figure 3 is a plot of the unprocessed tau records collected from each site. Site P1-5 is excluded from this figure because the tau data from this site was incomplete. This figure shows that a diurnal signal was present in all but one site, P4-4.

The sites still in question were examined further. P1-1 was not examined more closely due to complications while working with the data set. Figure 4 is a plot of a small section of the tau data from site P2-3. This is characteristic of the diurnal signal present at most of the sites. Of the remaining 20 sites, six sites (P1-4, P3-1, P4-2, P4-3, P5-1, and P5-2) had data sets that were affected by the time lockout that was set for each PIES. At these sites, the lockout was generally set to accept pings returning from objects up to 100 meters lower than the surface of the water. The other sites generally had lockouts corresponding to 350 to 450 meters below the water surface. In these six sites, the diurnal pattern was different from that shown in figure 4. There was no wave pattern to these diurnal signals. Figure 5 shows a diurnal signal from site P4-2 which is characteristic of these six sites.

The diurnal signals seem to have the same general properties in most of the data sets. The signal starts approximately 50 to 80 meters below the desired tau value level and has a depth range of between 170 and 200 meters. The time of day that the signal is at its deepest depth is between 10 AM and 3 PM. The diurnal signal is most often present and most prominent during the period between April and July. Many of the records exhibit the phenomenon at multiple seasonal periods. One other noticeable trait in common among about a third of the sites is that the last half of the travel time data contains little to no diurnal signal. Sites such as P3-3 and P1-6 have a substantial diurnal signal in the first half of the record and the second half has none.

5. Discussion

One possible explanation for this diurnal signal is the daily vertical migration of fish. It is a common occurrence when animals known as zooplankton move toward the water surface at night and move lower in the water column at night. The zooplankton try to maintain a preferred level of light intensity. Fish that eat the zooplankton also join in this migration (Gross 436). The theory fits the observation that the deepest depth was reached between 10 AM and 3 PM (1 AM and 6 AM GMT). This is the time period that the sun is at its highest intensity, and the zooplankton would be the lowest in the water column.

The daily vertical migration of zooplankton can be over 500 meters in range, and as deep as 700 meters (Gross 434-5). According to this, the migration present in the travel time data, which was approximately 200 meters and about 250 meters deep, is very reasonable. Another interesting observation relating to this was made while examining the CTD measurement of temperature at each PIES site. One measurement is plotted in Figure 6. Most of the temperature measurements show a small change between the surface and about 50 meters in depth, and at approximately 200 meters in depth the water column temperature becomes fairly unchanging. In this data set, the range and depth of the migration (approximately 200 and 250 meters, respectively) and the thermocline of the water are fairly similar.

If fish are the cause of this signal, what kind of fish might it be? One consideration is that the fish must have a body type that is optimum for reflecting the PIES ping. It is known that fish such as jellyfish and squid are not good sound reflectors, whereas the swim bladder of a fish is an excellent reflector (Gross 436). Therefore a fish with a swim bladder might be a prime candidate for causing this signal.

Another consideration is whether the signal is caused by large lone fish or by smaller fish in large schools. A lone fish makes a much smaller target for the PIES than a school of fish, making the probability that the school would reflect the pings much higher than that of the lone fish. However, in the data it seems that the closer the fish is/are to the PIES, the more likely the pings are to be reflected. At the maximum depth, there are many data points showing the fish. As the fish migrate(s) up the water column, fewer pings are returned early (refer to figure 4). This could indicate a smaller target such as the lone fish.

More evidence that this signal could be caused by such fish is the location of the sites exhibiting this feature the most. Looking at figures 2 and 3, it is obvious that the sites with the most diurnal signal are located closest to the Tsushima Strait or closest to the coast. These sites are generally more shallow than the other sites due to their location. For this reason and due

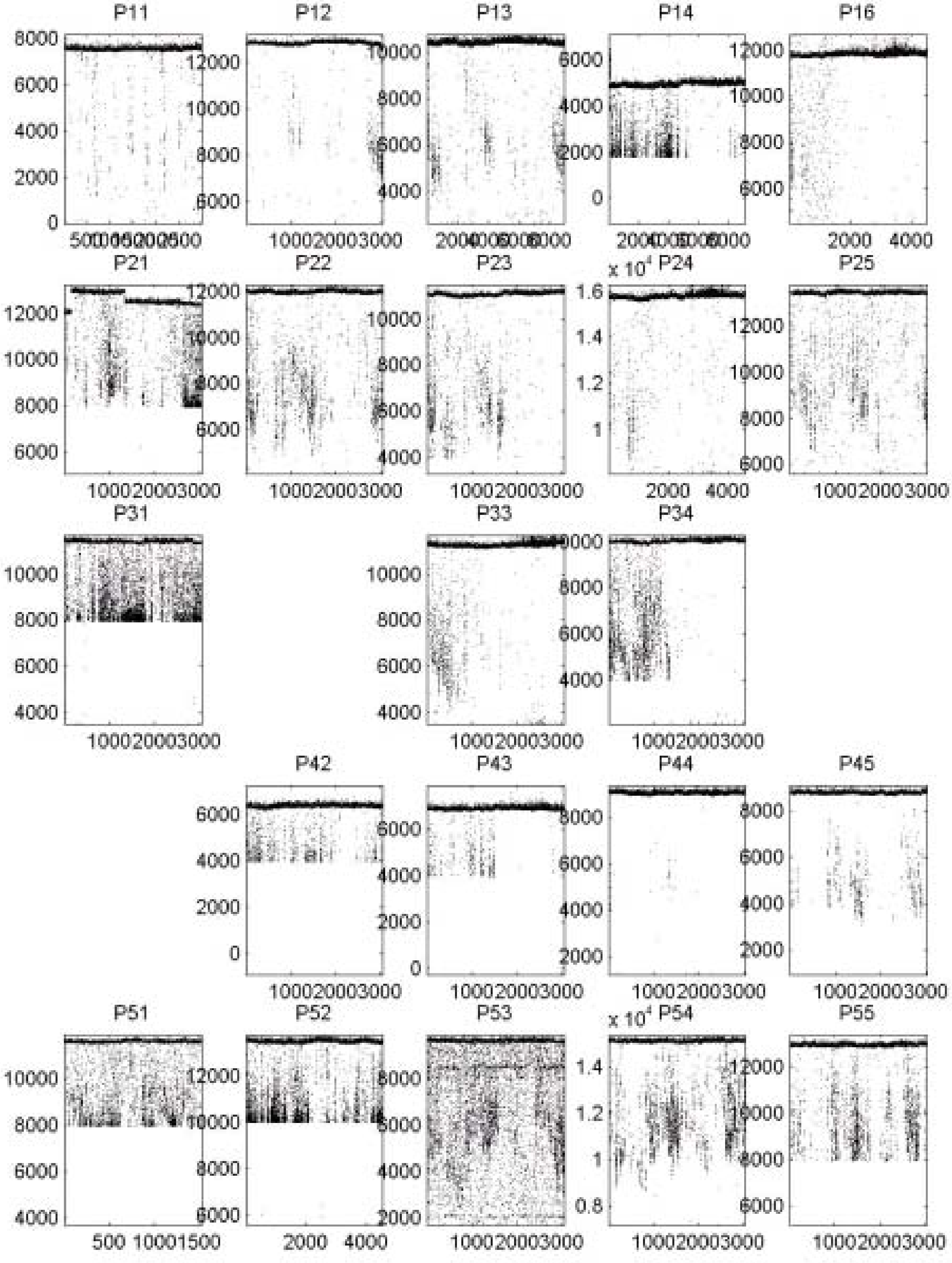

Figure 3. This is a plot of the unprocessed tau signal at each recovered PIES site. A diurnal signal was observed in these data records at 20 sites.

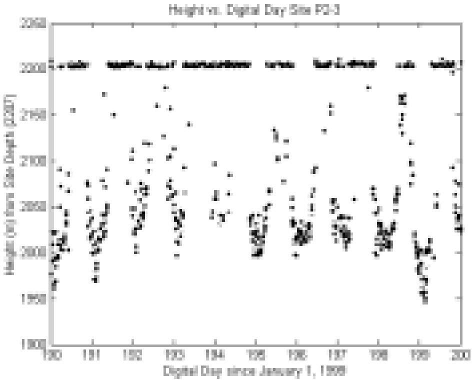

Figure 4. A diurnal signal was determined to be present in 20 PIES sites. This is a typical signal present in a plot of Height from the PIES vs. Digital Day. This signal is from site P2-3. Note that time series is in GMT, local time is 9 hours ahead of this.

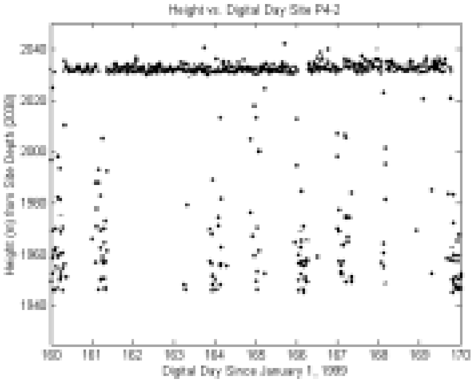

Figure 5. Six of the PIES sites that exhibited a diurnal signal were affected by the time lockout set for each PIES. This is a typical plot of Height from the PIES vs. Digital Day for these six sites. This signal is from site P4-2. Note that time series is in GMT, local time is 9 hours ahead of this.

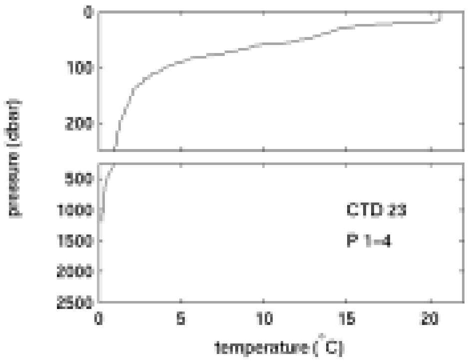

Figure 6. This is a plot of the temperature measurements recorded by a CTD cast at site P1-4.

to more current transport, it would be expected for more fish to be in these areas and the data to show a larger diurnal signal.

While looking at the raw travel time plots, it is obvious that this is a seasonal signal. It was determined that the months of April through July had the most diurnal signal. Further study of this seasonal variation was not completed. It would be interesting to look at the seasonal signal at each site to see how much the maximum depth of the migration changed over time as well as the migration depth range. It is not easily discerned whether the seasonal signals at each site are similar due to the time lockouts in some of the instruments and the lack of diurnal signal at other sites at various times. An explanation for the abrupt end of the signal half way through the two-year observational period would also be interesting to know.

6. Conclusions

During an observation time of 2 years, 25 PIES were recording the travel times of pings every hour in the Japan/East Sea. 23 of these instruments were recovered, and 22 of these had good travel time records. Of these 22 instruments, 20 were shown to exhibit a diurnal signal. Six of these 20 instruments experienced effects on the measurement of the diurnal signal due to the time lockout set for each PIES. The remaining fourteen instruments exhibited diurnal signals varying in density not only between instruments but also between seasons in the tau records at the different sites. There is strong evidence linking these diurnal signals to the daily vertical migration of fish that follow zooplankton in their daily migration.

The next step is to determine what fish is causing this diurnal signal, if it can be determined. Further investigation of the travel time records will most likely be necessary in order to accomplish this. These investigations might include determining the seasonal signal in each record or trying to see if any migration occurs from site to site. If this fish can be pinpointed, this observational data could be very helpful to an interested biological scientist.

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