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2004년 10월 및 11월에 관측된 가막만의 물리환경

이문옥[1,†] · 김병국[1] · 박성진[2] · 김종규[1]
[1]여수대학교 해양공학과
[2](주)지오시스템 해양사업부

Some physical characteristics of Gamak Bay observed in October and November of year 2004

Moon Ock Lee[1,†], Byeong Kuk Kim[1], Sung Jin Park[2] and Jong Kyu Kim[1]
[1]Department of Ocean Engineering, Yosu National University, San 96-1 Doondeok-Dong, Yeosu 550-749, Korea
[2]GeoSystem Research Corp., Gunpo, Gyeonggi-Do, 435-824, Korea

요 약

우리 나라 4대 굴양식 어장 중의 하나인 가막만의 물리환경을 조사하기 위해 2004년 10월부터 11월까지 약 1개월간 조석, 조류 및 수온을 연속관측하고 그 결과를 분석하였다. 조석은 가막만의 북동 수로와 남쪽 만구를 통해 거의 동시에 같은 크기로 유출입하지만, 북서 내만역은 진폭과 위상에 있어서 약간의 차이를 보였다. 만내에 존재하는 3개의 수괴를 구분 짓는 전선 부근에서 측정한 수온의 시계열은 북서 내만역을 제외하고는 조석에 따라 만조시에는 상승하고 간조시에는 하강하는 매우 민감한 반응을 나타내었다. 특히 만의 동쪽 평사리 부근에서의 수온은 기온에 의해 강한 영향을 받는다는 사실을 이 등 [1990]의 결과와의 비교를 통해 확인하였다. 일반적으로 정체수역으로 알려진 만의 북서쪽에서는 바람에 의한 영향으로 저층 부근에서 표층 흐름에 역류하는 상당한 크기의 유속을 가진 흐름의 존재가 확인되었다. 본 조사기간 동안 측정된 조류의 누적평균 이동 방향과 그 크기는 대체로 이 등 [2004]에 의한 2차원 유동계산결과와 잘 일치하였다. 그러나, 만의 북서쪽에서의 흐름은 다소 과대평가되었는데, 이것은 관측기간동안 북서풍이 탁월하게 불었고 또한 이 등 [2004]에 의한 계산결과가 대조기만을 대상으로 한 흐름 패턴이었기 때문으로 판단되었다.

Abstract – Field observations have been conducted to investigate the physical environment around oyster farms in Gamak Bay. Tidal waves near the two channels at the northeast and south of the bay had almost the same amplitudes and phases. Water temperature responded sensibly to the tides, rising at high water and falling at low water, except for the northwest region. The currents more regularly varied in accordance with a tidal period as long as they are at the faster-flowing region. A considerable flow has been found near the seabed of the northwest of the bay, normally known to be a stagnant area, and also the flow was opposite to the surface flow. Average moving speeds and directions of the flow at each station coincided well with patterns of the residual currents computed by Lee *et al.* [2004], except for the northwest region. The discrepancy for the northwest region is not clear but it may have resulted from the facts that the computed flow pattern represents only the case of spring tide and in addition, a northwesterly wind prevailed all the observation time.

Keywords: Gamak Bay(가막만), Oyster farms(굴양식장), Seawater movement(해수유동), Water masses (수괴), Residual currents(잔차류), Harmonic analysis(조화분해)

[†] Corresponding author: leemo@yosu.ac.kr

1. Introduction

Gamak Bay is a semi-enclosed area of shallow water with a mean depth of 9 m and has both east and south channels to receive the seawater from outside (see Fig. 1). Gamak Bay also has an egg-shaped sea surface area of approximately 112 km^2. This bay is specifically well known as one of major oyster production areas since last few decades. Fig. 2 represents the distribution of oyster farms, in February 2002, where the key denotes the amount of oyster production (kg) per hanging string of 100 m. Also, this figure shows three water masses, identified by Lee *et al.* [1990]. We notice that oyster farms are densely distributed within the outer bay water as well as at the south of the inner bay water while no farms exist around the northwest area of the bay. This implies that oyster farms properly take advantage of seawater movement in the bay. Cho *et al.* [1996] estimated the carrying capacity of Gamak Bay to be approximately 21 ton per unit ha per year, based on a primary production by phytoplankton. However, Park *et al.* [2002] pointed out that it might have been estimated to be a little bit exaggerated because they assumed that all the phytoplankton within the bay varies into oyster body weight. According to statistics (Yeosu Oyster Fisheries Cooperative Society [2004]), last year the number of culture facility turned out to be 20 ton per unit ha. This explains that current situation reached nearly the maximum oyster production acceptable in the bay. Furthermore, owing to an inappropriate management of fishing grounds and an inflow of partially treated sewage (Cho *et al.* [1994]; Kim *et al.* [2003]; MOMAF [2001]), the water quality in the bay is getting worse than before. In particular, since a large scale of water front development has been recently scheduled (Yeosu City [2002]), not only seawater movements but also the water quality is expected to largely alter. Thus, the status of oyster production area is threatened.

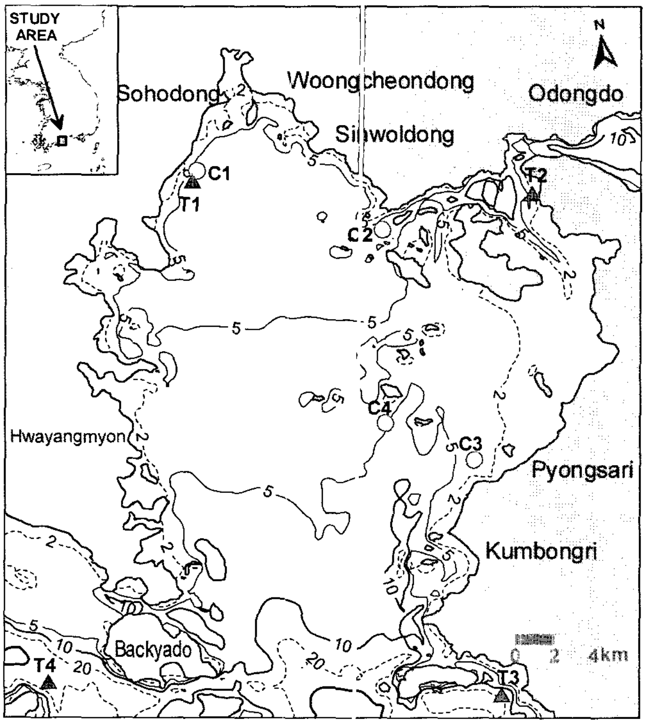


Fig. 1. Study area and oceanographic stations in Gamak Bay (C1~C4 are current measurement stations and T1~T4 are tide observation stations and Arabic numbers are depth in meter below the datum level).

On the other hand, most of the contaminants come in through the northwest of the bay. Furthermore, the shoal, which exists between two isobaths of 5m across from the east to the west at the mid of the bay, makes it difficult to communicate between the inner bay waters and outer bay waters (Cho *et al.* [1994]; Lee *et al.* [2002]; Lee *et al.* [2004]). Lee *et al.* [1995] claimed that the north area of the bay has a unique depositional environment than any other regions in the bay since seawater movements affect the distribution of surface sediment. It suggests that a shoal existing around the mid of the bay inhibits flow exchanges between the outer bay water. Lee *et al.* [2002] also pointed out that three water masses formed within the bay are closely related to the bathymetry.

That is, the water masses and bottom topography might be strongly interactive with each other. Lee *et al.* [1995] elucidated that tidal currents inside Gamak Bay were strongly affected by the wind. Although Gamak Bay is comparatively shallow water with an average depth of 9 m, wind-driven currents are expected to play a minor role for the whole flow (Pond *et al.* [1983]). In particular, Lee *et al.* [2004] evaluated the autumn wind to play an important role for the growth of oyster.

The objectives of this study are to investigate physical movements of water masses around oyster farms in Gamak Bay. For this purpose, tides, currents and water temperature were observed for about a month.

2. Materials and Methods

A field observation has been conducted to gather data of tides, currents and water temperature at stations shown in Fig. 1, from October 21 to November 22, 2004. The instruments used in the field survey were Aanderra current meters RCM9 (at stations C3 and C4) and RCM7 (at station C2), ADCP (Acoustic Doppler Current Profiler) (at stations C1 and T1), and RBR tidal gauge XR-420 (at station T2~T4). These four current meters were

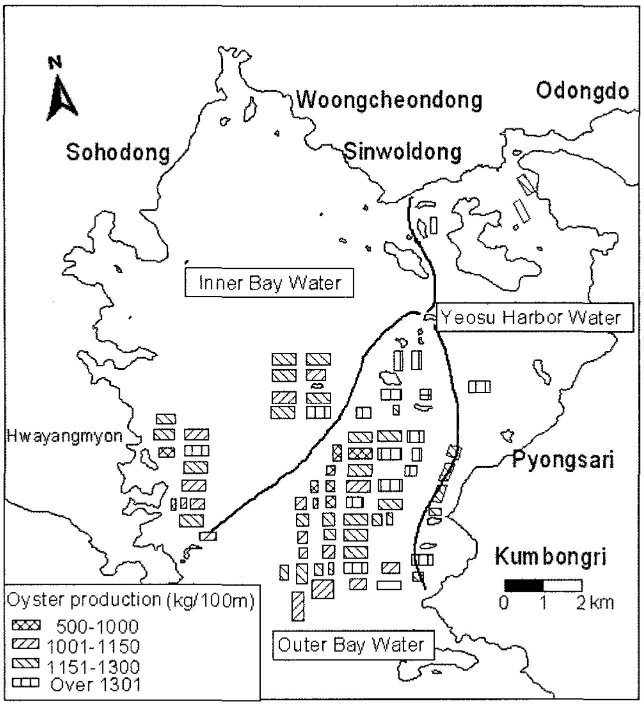


Fig. 2. Oyster farms and three water masses distributed in Gamak Bay.

deployed considering distributions of three water masses such as Yeosu Harbor Water, Inner Bay Water and Outer Bay Water, as shown in Fig. 2. That is, these four stations (C1~C4) were chosen to represent physical characteristics of individual water mass or distinguish from one another. Likely, stations (T1~T4) were chosen to grasp tidal characteristics coming into the bay and then use as open boundary conditions in numerical experiments. In particular, the ADCP was deployed at station C1 in order to elucidate a three-dimensional flow structure at the northwest of the bay. Aanderra current meters were mounted at 2 m below the sea surface, and the ADCP was set on a seabed to be able to acquire the data of every 0.5 m interval from 1.5 m above the seabed to the sea surface. However, unfortunately, a tidal data for T4 could not be acquired because the instrument was lost while observing. Water temperatures were measured by sensors attached to Aanderaa current meters or the ADCP. All data was set to be read in with every 10 minutes interval. Thirty-year air temperature and wind data from 1971 to 2000 were also used for analysis (the Yeosu Observatory [2004]).

3. Characteristics of Seawater Movements in Gamak Bay

3.1. Tides

Fig. 3 represents a time series of the tides observed at stations T1~T3. The initial water level observed at each station was corrected by a sea level pressure. A tidal data acquired from the

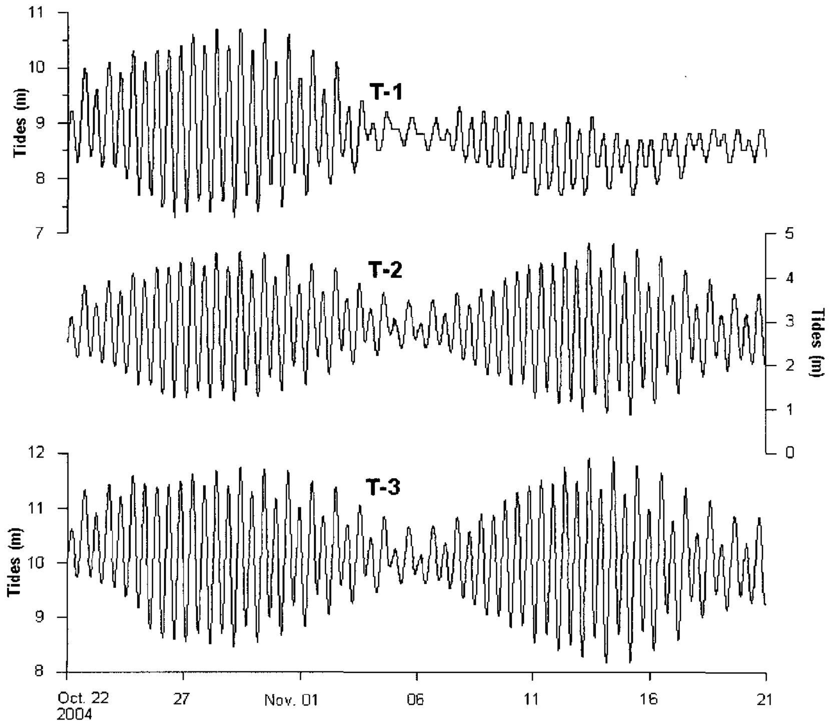


Fig. 3. Time series of the tides observed at stations T1~T3.

Table 1. Tidal harmonic constituents for each station

Stations	M_2		S_2		K_1		O_1	
	H(m)	(°)	H(m)	(°)	H(m)	(°ý)	H(m)	(°)
Dolsandaegyo (T2)	1.01	266.7	0.45	299.3	0.21	190.7	0.14	157.1
Songdo (T3)	0.98	265.0	0.43	297.1	0.20	188.8	0.15	157.4
Sohodong* (T1)	0.95	265.7	0.47	293.1	0.19	172.2	0.19	159.7

*Yeosu city [2002]

Table 2. Tidal harmonic constituents at Yeosu Harbor and Songdo (Lee *et al.*[1995])

Stations	M_2		S_2		K_1		O_1	
	H(m)	(°)	H(m)	(°)	H(m)	(°)	H(m)	(°)
Yeosu Harbor	0.96	2.7	0.49	26.0	0.21	46.7	0.12	25.7
Songdo	0.94	4.9	0.47	28.3	0.21	50.5	0.13	28.4

ADCP at T1 near Sohodong seemed to be normal until November 3 but after that it turned out to be abnormal without any reason. Thus, only a normal data of the tides at T1 was interpreted and compared to the other data obtained from T2 and T3. As a result, these all the data showed a regular variation with a semi-diurnal period. Table 1 indicates amplitudes and phases of four major constituents obtained by a harmonic analysis of these actual tides, using the TASK 2000 software. Here phases are values for Greenwich Standard Time. For Sohodong, a harmonic analysis data was adopted, given by Yeosu City [2002] from April 3 through April 17, 2002, because the position (34°43.9N, 127°40.1E) is similar to T1 (34°43.7N, 127°38.9E).

According to Table 1, a tidal harmonic constituent at T1, e.g. Sohodong, located at the northwest of the bay, has a little difference from the ones at T2 and T3, located at the northeast and south mouth. On the contrary, tidal waves, coming in through the narrow channel of northeast (T2) and south mouth (T3), are nearly equivalent in their amplitudes and phases. This suggests that a similar size of tidal waves almost simultaneously comes in or goes out through the two channels. Also, for non-harmonic constituents of the tides, mean high water intervals are 9h 12m at Dolsandaegyo, 9h 8 m at Songdo and 9h 10 m at Sohodong, respectively and spring ranges are 293.2 cm at Dolsandaegyo, 282.2 cm at Songdo and 284.0 cm at Sohodong. In addition, mean sea levels are 181.9 cm at Dolsandaegyo, 176.0 cm at Songdo and 180.0 cm at Sohodong. These mean sea levels here

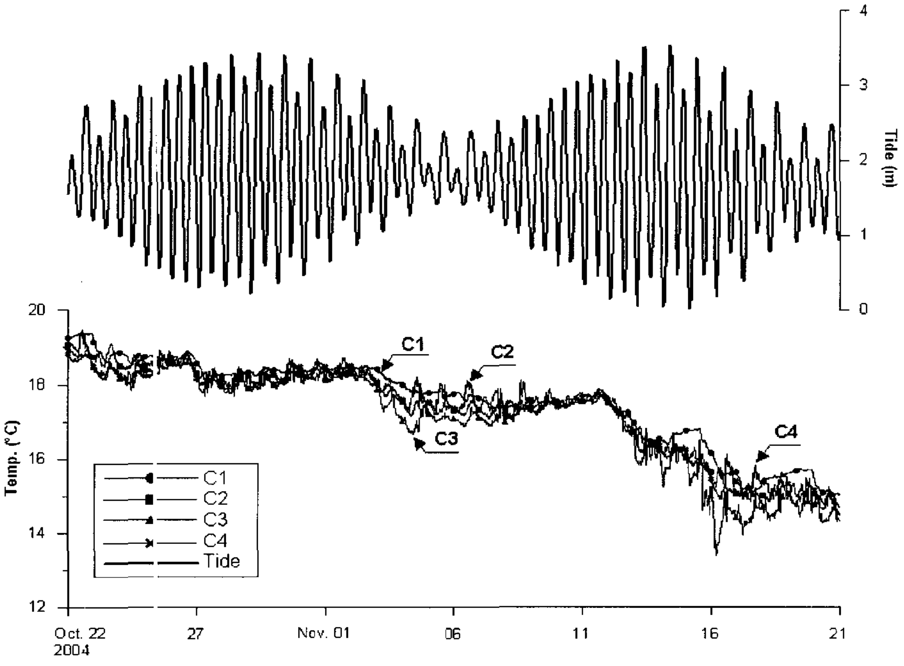


Fig. 4. Time series of water temperature measured at each station.

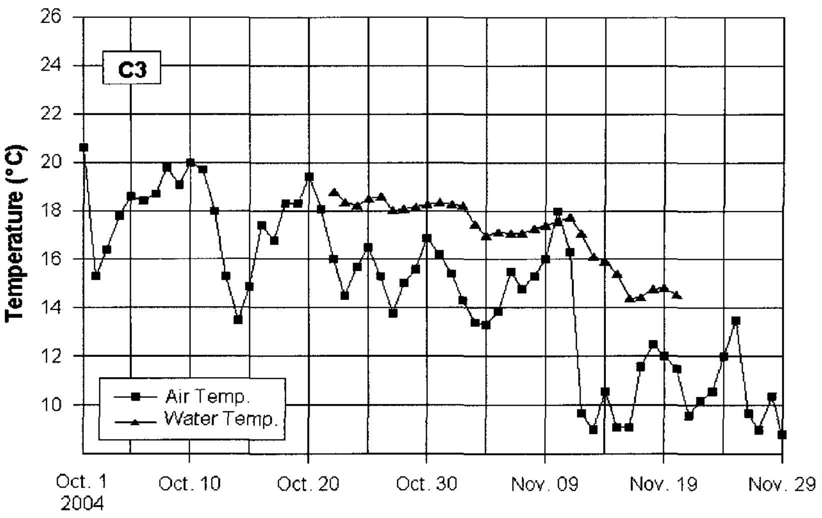


Fig. 5. Relationship of air temperature and water temperature at station C3.

are 181.0 cm higher than a datum, where a water level is 0. On the contrary, the form ratio of tides is 0.24 at Dolsandaegyo, 0.25 at Songdo and 0.27 at Sohodong, respectively. Thus, a semi-diurnal tide is dominant in the study area.

On the other hand, in Table 2, tidal harmonic constituents for Yeosu Harbor and Songdo, obtained by Lee *et al.* [1994], are indicated. Comparing these two cases to the results in Table 1, the tides at Yeosu Harbor and Songdo, by Lee *et al.* [1995], are more or less similar for amplitudes, but very much different for phases, comparing with the ones at T2 and T3. This discrepancy may result from the difference in duration of the observation; Lee *et al.* [1995] just used the data acquired for about 17 days. However, the form ratio of the tides by them was 0.25, similar to authors'.

3.2. *Time series of water temperature*

Fig. 4 shows time series of water temperature at each station measured during the observation time. Here, the actual tides recorded at the Yeosu Observatory during the same period were introduced together. Water temperature has a tendency to gradually drop so that at the end of November it went down more than 4 compared to 18~19 at the end of October. Also, water temperature at C1, located at the northwest of the bay, seems to be less sensitive to the tides and is a bit higher than the one at any other regions C2~C4. The insensitivity at C1 might attribute to the fact that the temperature at C1 was measured by the ADCP on the seabed (9 m in depth), differently from the other stations. Also, according to Lee *et al.* [1990], the reason why the temperature at C1 was so high is probably because C1 is located at the position

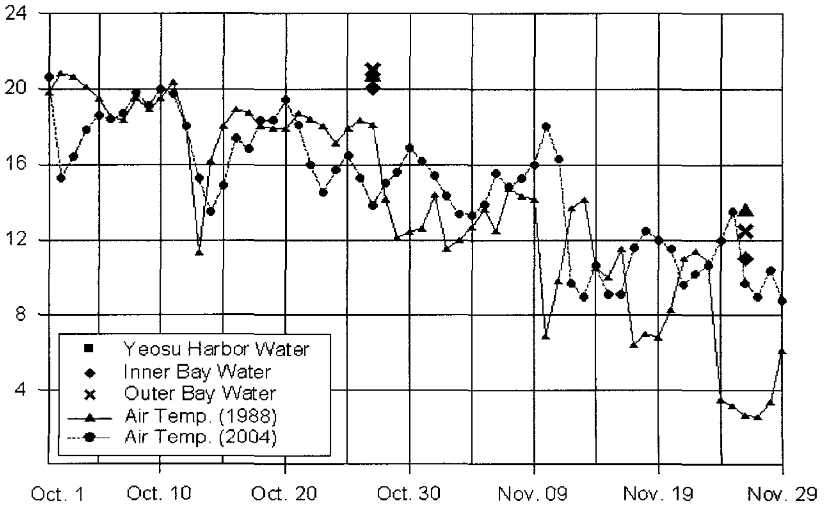


Fig. 6. Relationship of air temperatures and water temperatures for three water masses in Gamak Bay.

representative of Inner Bay Water that has the highest temperature among three water masses appearing in the bay.

Fig. 5 illustrates the relationship of air temperature in Yeosu and water temperature at C3 during the observation time. We notice that water temperature at station C3 tends to be approximately 3 higher than the air temperature and it also seems to vary in accordance with a variation of air temperature. This implies that air temperature is one of most important factors to determine the water temperature *in situ*. In addition, Fig. 6 represents the relationship of air temperatures in 1988 and 2004 and water temperature for three water masses during the observation time. Air temperature on the 27th of October, 1988 was about 4 higher while air temperature on the 26th of November, 1988 was about 7 lower, than those days of 2004. Also, here are water temperatures for three water masses, measured by Lee *et al.* [1990]. The water temperature of these water masses appeared a bit higher on the 27th of October 1988 while it is expected to be a bit lower on the 26th of November 1988, compared to the same days in 2004. This consequence can be attributed to the difference of air temperature between 1988 and 2004, in reference to Fig. 5. On the other hand, water temperatures at stations C2~C4 responded sensibly to the tides, rising at high water and falling at low water. Particularly, the sensitivity at C2 was extremely significant and the response to the tides was faster than the one at C3 or C4.

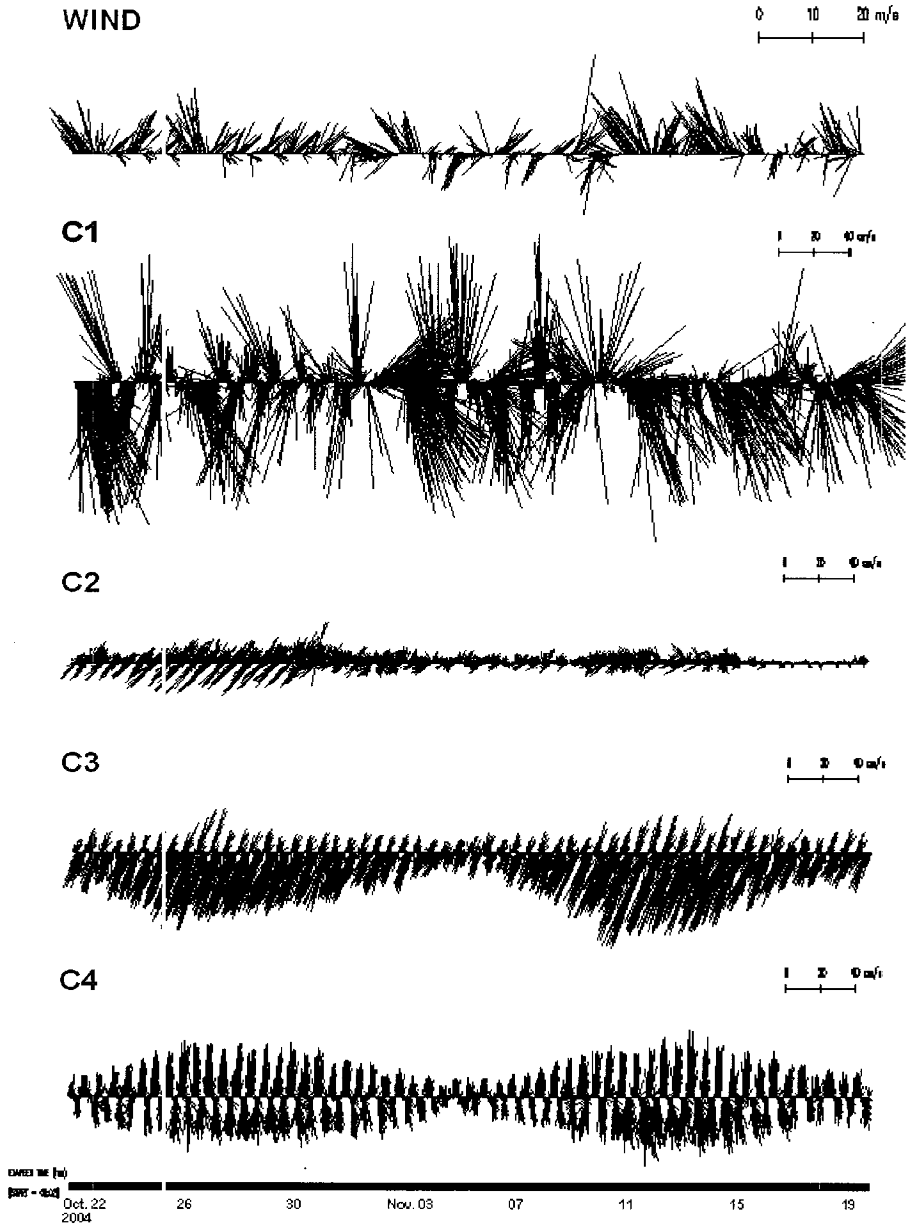


Fig. 7. Stick diagrams for the daily average winds and tidal currents at each station.

This reflects a phase lag that takes tidal waves to arrive at the stations C3 or C4 from the station C2 after coming in through the northeast or south channel.

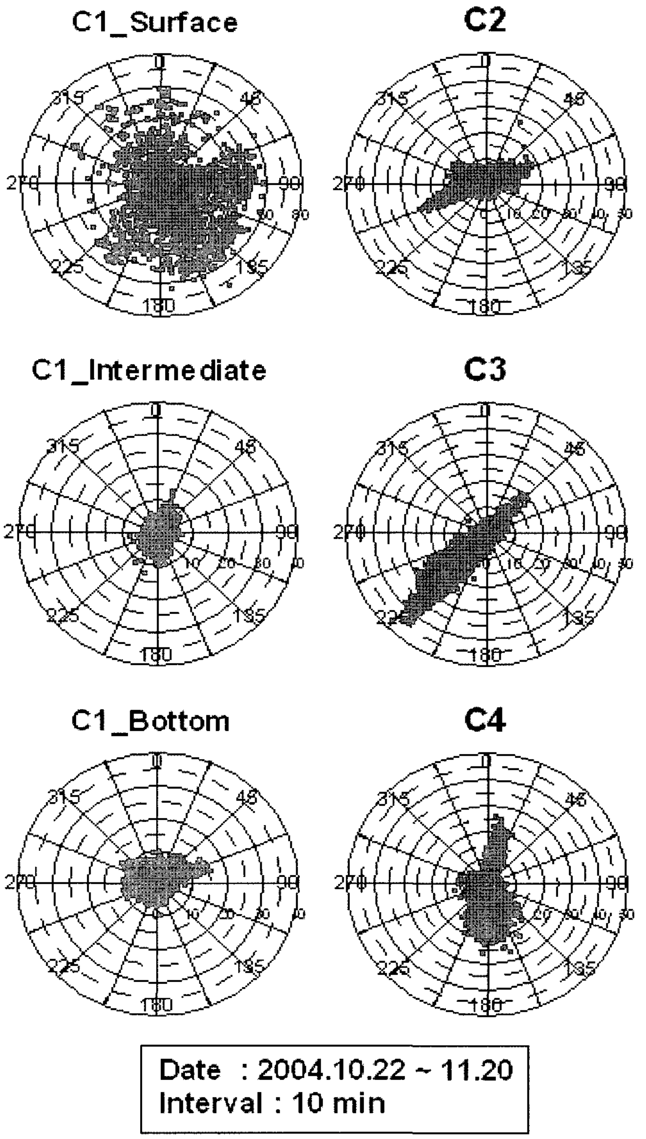
3.3. Stick diagram of tidal currents

Fig. 7 represents time series of daily average winds in Yeosu during the observation and tidal currents measured for a month at stations C1~C4. The northwest or northeast winds prevailed rather than the south wind during the observation time. Tidal currents at C1 vary south-northward with a small magnitude. Observation shows that the flow velocity at C1 markedly increased near the spring tide. This was probably caused by a disturbing action of wind. On the other hand, tidal currents at C2, where is under the influence of Yeosu Harbor Water through the northeast channel, head for the northeast or the southwest overall but dominantly for the southwest, regularly varying in accordance with the tides.

However, unfortunately after November 4th, a lot of marine organisms adhered to the rotor of the current meter to hinder the measurement of the flow. The tidal currents at C3, where simultaneously receives the influence of Yeosu Harbor Water and Outer Bay Water through the northeast channel and south mouth, are very active. The flow regularly varies from northeastward to southwestward according to the tides but the southwestward flow is more likely prevalent. The station C4 is located at the region to receive both of Inner Bay Water and Outer Bay Water so that the flow is fairly active, just like C3. At station C4, northward and southward flows are almost equivalent with each other and alternately appear with the tides.

3.4. Variance diagram of currents

Variance diagrams for the currents measured at each station are indicated in Fig. 8. Firstly, a variance diagram for C1, where the currents were measured by the ADCP, shows a wide range of variance at the surface but it is small at the intermediate layer. Also, the velocities appeared less than 60 cm/s at the surface, 10 cm/s at the intermediate layer and 20 cm/s at the bottom, indicating that a considerable flow exists even near the bottom. A main direction of the flow seems to be southeastward at the surface while the NNE or SSW flows at the intermediate layer and the NE or ENE flows at the bottom. It is therefore suggested that a surface flow at C1 is possibly opposed to the flow at intermediate layer or at the bottom. Secondly, the flow at C2 took mainly the ENE or WSW directions while the SW directions at C3 and the NNE or S directions at C4.


C1_Surface C2

C1_Intermediate C3

C1_Bottom C4

Date : 2004.10.22 ~ 11.20
Interval : 10 min

Fig. 8. Variance diagrams for the tidal currents measured at each station.

3.5. Progressive diagram of currents

Fig. 9 is progressive diagrams for accumulated surface currents since the observation has been started at each station. At C1, the surface flow headed for the southeast overall while a surface flow at C2 headed for the northwest so that it is almost opposite to the flow at C1. On the contrary, the surface flow at C3 headed for the southwest and the southeast at C4, respectively. An average moving speed of the flow at each station was 5.7 cm/s at C1, 0.9 cm/s at C2, 7.2 cm/s at C3 and 0.8 cm/s at C4 so that the flow at C3 turned out to be most strong. Fig. 10 compares these average moving speeds of the flow at each station with the computed residual currents by Lee *et al.* [2004], using a two-dimensional numerical model, in consideration of a northwesterly wind prevailed during the observation time. Here they used values of four major constituents obtained by Lee *et al.* [1995], as indicated in Table 2. The result showed that average directions

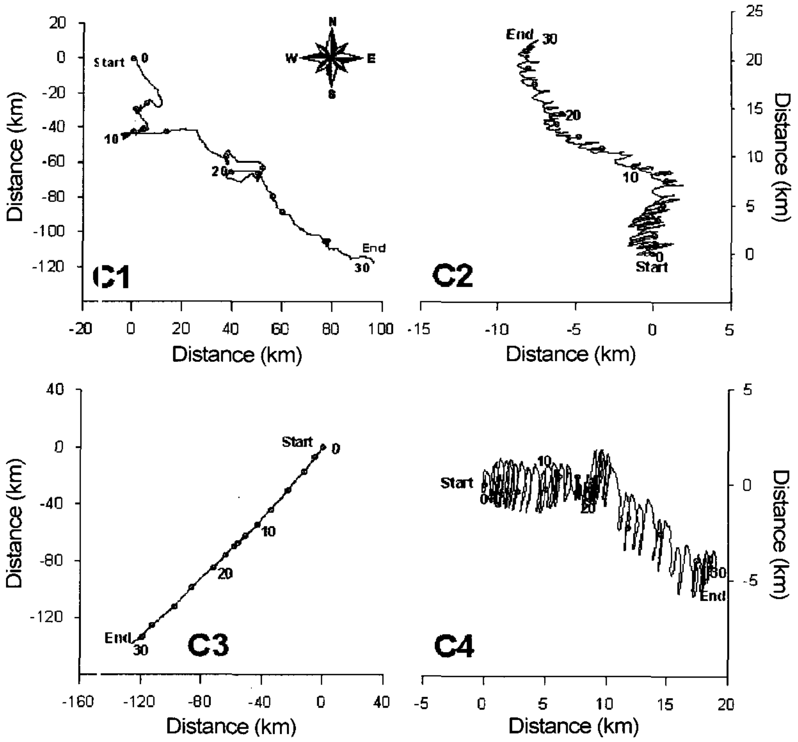


Fig. 9. Progressive diagrams of the accumulated surface currents at each station.

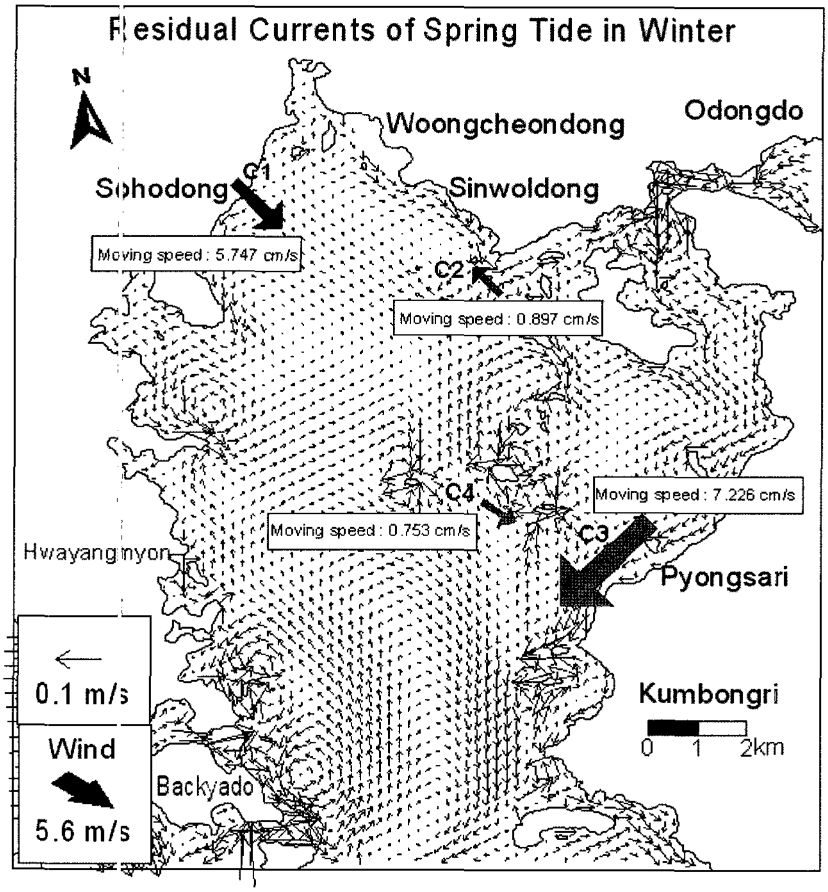


Fig. 10. Comparison of the drift of the surface currents at each station and computed residual currents.

and speeds of the drift of the currents look well coincident with the residual currents except for C1. The discrepancy for C1 is not clear yet but it is inferred that because the computed residual currents represent only the case of spring tide and in particular, a northwesterly wind prevailed all the observation time.

4. Conclusions

Physical environments have been investigated from October through November 2004 in Gamak Bay where is one of the major oyster production areas in Korea. Tidal harmonic constituents had no difference between two stations locating near the channels at the northeast and south. Thus, a similar size of tidal waves almost simultaneously comes in or goes out through these two channels but their amplitudes and phases were largely different from those by Lee *et al.* [1995]. Water temperature seemed to sensibly respond according to the tides, rising at high water and falling at low water but it turned out to be insensitive to the variation of the tides at the northwest of the bay. Currents at the northwest of the bay, where the flow is usually weak, appeared to be extremely strong near the spring tide. This can be probably caused by a disturbing action of wind when a tidal current became strong. Variance diagrams for the currents showed that a considerable flow exists near the bottom of the northwest area and it is opposite to the surface flow. This will have to be considered in computing a mass transport since the flow affects the eutrophicated processes or sedimentation rates at the northwest area of the bay (Park *et al.* [2004]; Kim[2002]).

Average speeds and directions of the drift of the currents coincided well with the computed residual currents obtained by Lee *et al.* [2004], in consideration of a prevailing wind for the observation time. However, it appeared relatively exaggerated at the northwest of the bay, compared to the flow observed at an ordinary state. The discrepancy for C1 is not clear yet but it is inferred that because the computational result represents only the case of spring tide and in addition, a prevailing wind acted on the northwest all the observation time.

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2005년 3월 4일 원고접수
2005년 10월 20일 수정본 채택