The Journal of the Oceanological Society of Korea
Vol. 20, No. 3, p. 6~19, December 1985.

Structure of Upwelling off the Southeast Coast of Korea

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夏季 韓國 南東海岸의 湧昇의 構造

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Abstract: Hydrographic data and daily time series of longshore wind, sea level and sea surface temperature were used in order to explain why the upwelling effect in SST is especially prominent near Ulgi-Gampo although the sea level records along the whole southeast coast show a nearly uniform upwelling-downwelling response to wind. Regional difference in intensity of the wind-induced upwelling represented by the SST decrease is attributed to the combined influence of two factors; one is the baroclinic tilting of isotherms due to the East Korea Warm Current (EKWC) near the Ulgi-Gampo coast, the other is the topographic effects around the southeast coast. Baroclinic tilting effect of EKWC which is generally strongest near the coast of Ulgi to Gampo results in both of the shoaling of cold water and the westward trapping of the coldest bottom water over the shallower shelf rather than the deepest trough region off that coast regardless of the season. Therefore, becacse of the cold water ready for upwelling at the subsurface layer, SST responds very rapidly to the upwelling-favorable winds of summer only off the Ulgi-Gampo coast. Spreading isobaths from Pusan to Gampo can reinforce the upwelling of the cold bottom water and its westward trapping.

要約: 한국 남동해안의 풍향에 따른 거의 균일한 용승현상 중 특히 울기—감포 근해역에 현저하게 나타나는 용승의 원인을 해양관측 자료와 기상, 해수면 변위 및 표층수온의 일변화 자료를 이용하여 연구하였다. 바람에 의한 용승현상이 강도에 있어 지역적인 차이를 보이는 것은 두가지 요인의 복합적인 영향에 기인한다. 첫째로 울기—감포해안에 발달한 동한난류(EKWC)로 인한 등온선의 baroclinic tilting 요인과 둘째로 남동해안 주변의 지형적 영향을 들 수 있다. 동한난류의 baroclinic tilting효과는 대체로 울기—감포해안 근처에서 가장 강하게 나타나며, 이로 인해 계절에 관계없이 얕은 대륙붕위로 저층냉수가 편중되어 나타난다. 따라서 표면 가까이 용승에 의한 냉수괴가 존재하며 결국 울기—감포해안에서만 여름에 바람에 의한 용승으로 표층수온이 낮게 나타난다. 또한 부산에서 감포에 이르는 평탄한 연안 해저지형도 저층냉수의 용승을 증가시키는 작용을 한다.

INTRODUCTION

It has long been known that the cold water mass appears at the sea surface near Ulgi (Ulsan) every summer (Lim and Chang, 1969; An, 1974; Seung, 1974). Lee (1983) stated that the variations in sea level and sea surface temperature (SST) at Ulgi and Gampo are highly correlated with longshore winds. According to his analysis, sea levels at Pusan, Ulsan and Pohang fluctuate in nearly the same fashion, which means that sea level consistently shows an upwelling-downwelling response to the Ekman transport by longshore wind along the whole southeast coast of Korea. However, SST decreases only at Ulgi and Gampo during upwelling, but not at Pusan and Pohang (Janggigab). Furthermore, the amount of SST decrease is usually greater at Gampo than at Ulgi. No one has given any plausible explanation on this regional difference in upwelling intensity represented by SST change.

Local intensification of upwelling has been studied in the famous upwelling regions. Arthur (1965) demonstrated that the upwelling could be reinforced equatorward of a cape for the eastern boundary current following the coastline. Johnson et al. (1980) observed that the upwelling was intensified in downstream region of the cape near Valparaiso, Chile. A numerical simulation by Peffley and O'Brien (1976) shows that the bottom topography around the Cape Blanco, not the cape itself, is responsible for the regional difference in the wind-induced upwelling off the Oregon coast. Blanton et al. (1981) and Leming and Mooers (1981) studied the topographically induced upwelling on the South Atlantic Bight shelf shallower than 200m, and Lee, et al. (1981) described the upwelling caused by the cyclonic eddy in the same region. Freeman and Denman (1982) also studied the topographically controlled upwelling off the southern Vancouver Island. Janowitz and Pietrafesa (1982) made a theoretical model of the topographically induced upwelling.

For the Tsushima Current flowing northeastward through the Korea Strait, southeast coast of Korea may act as a large cape. In addition, peculiar topographic features such as the narrowing width and elongated trough of the strait, diverging bathymetry from Pusan to Gampo and the abrupt increase of bottom depth off Gampo (Fig. 1) may have a significant influence on the coastal upwelling as well as on the Tsushima Current. The main objective of this study is, by means of the hydrographic data available, to explain why the upwelling effect in temperature is especially salient in the Ulgi-Gampo region despite that the wind condition and the sea level variations are almost the same over the southeast coast.

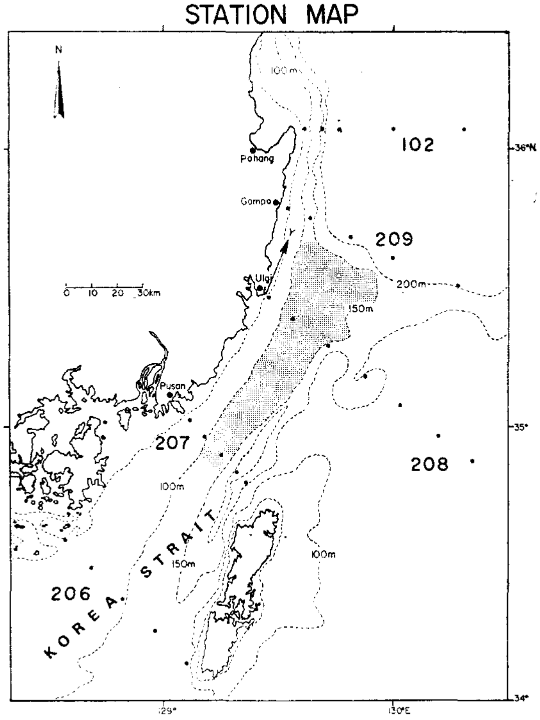

Fig. 1. Location map and bottom topography off the southeast coast of Korea. Stippled area depicts the diverging isobaths.

DATA

Daily time series of longshore wind (y-component at Ulgi in Fig. 1), sea level and SST were excerpted from the data of Lee (1983). In order to study the evolution of hydrographic fields related with temporal variations in wind forcing, the repeated surveys with short periods accompanied by the continuous wind and current measurements are desirable. However, the hydrographic data available at present are mostly from the results of bimonthly routine survey by the National Fisheries Research and Development Agency (FRDA). Therefore it is only possible to compare the every hydrographic field with the wind conditions in order to infer the general relationships between them. Among hydrographic data, there were only three cases in August of 1973, 1976 and 1978 in which the periods of the hydrographic observation and the enhanced upwelling were coincided with each other. In August 1974, a data set pertaining to a typical downwelling event was made. These four cases are studied in detail. In separating the components of wind at Pusan, NNE direction which is tangential to the coast at Ulgi was taken as the positive y-axis (Fig. 1).

Mean values of hydrographic data in the Oceanographic Handbook of the Neighbouring Seas of Korea published by FRDA (1979) were also used for the description of the average states of temperature or density fields and the distribution of bottom water temperatures.

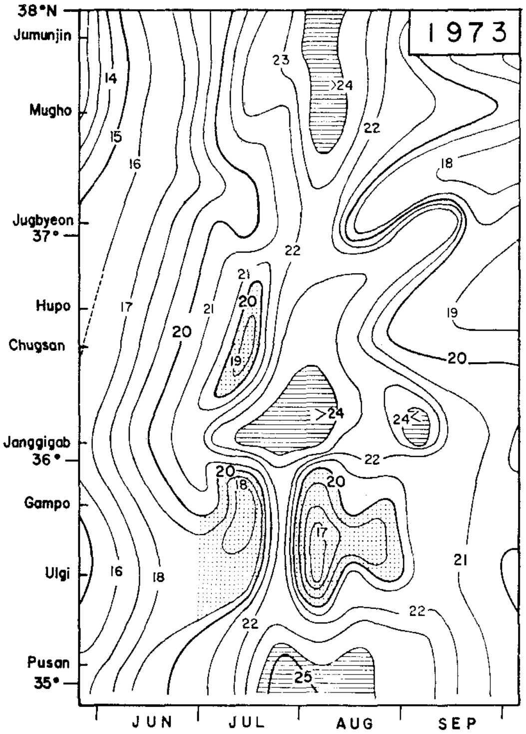

Fig. 2. Variations of 10-day mean SST along the east coast in summer 1973 (Lee, 1983).

RESULTS AND DISCUSSION

Variations in 10-day mean SST along the east coast in summer 1973 (Fig. 2) is used as an example to illustrate that, among the southeast coast from Pusan to Janggigab (Pohang), SST is particularly low at Ulgi and Gampo. SST variations at Pusan and Janggigab are considered to be normal because they have maximum values in summer. From the daily time series of longshore wind, barometrically adjusted sea level and SST (Fig. 3), it is recognized that not only sea levels at Pohang, Ulsan (Ulgi) and Pusan but also SST's at Gampo and Ulgi show good inverse correlation with longshore wind at Pusan. During the periods of persistent wind favorable for upwelling (positive y-component), depressed state of sea level and decrease in SST are apparent. On the contrary, SST increases frequently at Pusan and Janggigab during the period of major upwelling events at Ulgi and Gampo (Lee, 1983). A noticeable fact is that the sea level varies in nearly the same manner at three stations of Pohang, Ulsan and Pusan in response to longshore wind. This result suggests that the offshore Ekman transport has nearly the same influence on the sea level variations at three stasions. Then the upwelling effect on SST will depend on whether there is the cold water to be upwelled at subsurface layer. For example, the depth at which the upwelling of subsurface cold water occurs is about 25~60m for short period upwelling off the coasts of Oregon and NW Africa (Halpern, 1976; 1977).

Vertical sections of mean temperature (Fig. 4) in August off Pusan (Line 207), Ulsan (Line 208), Gampo (Line 209) and Pohang (Line 102) represent the average hydrographic structure of summer off the southeast coast. Arbitrary reference layer of cold water of 14~15°C is hatched. On Line 207 off Pusan, slope of isotherms in the upper layer is greatest between St. 4 and St. 5 which is consistent with the results of Lee (1970, 1974) that the strongest Tsushima Current is

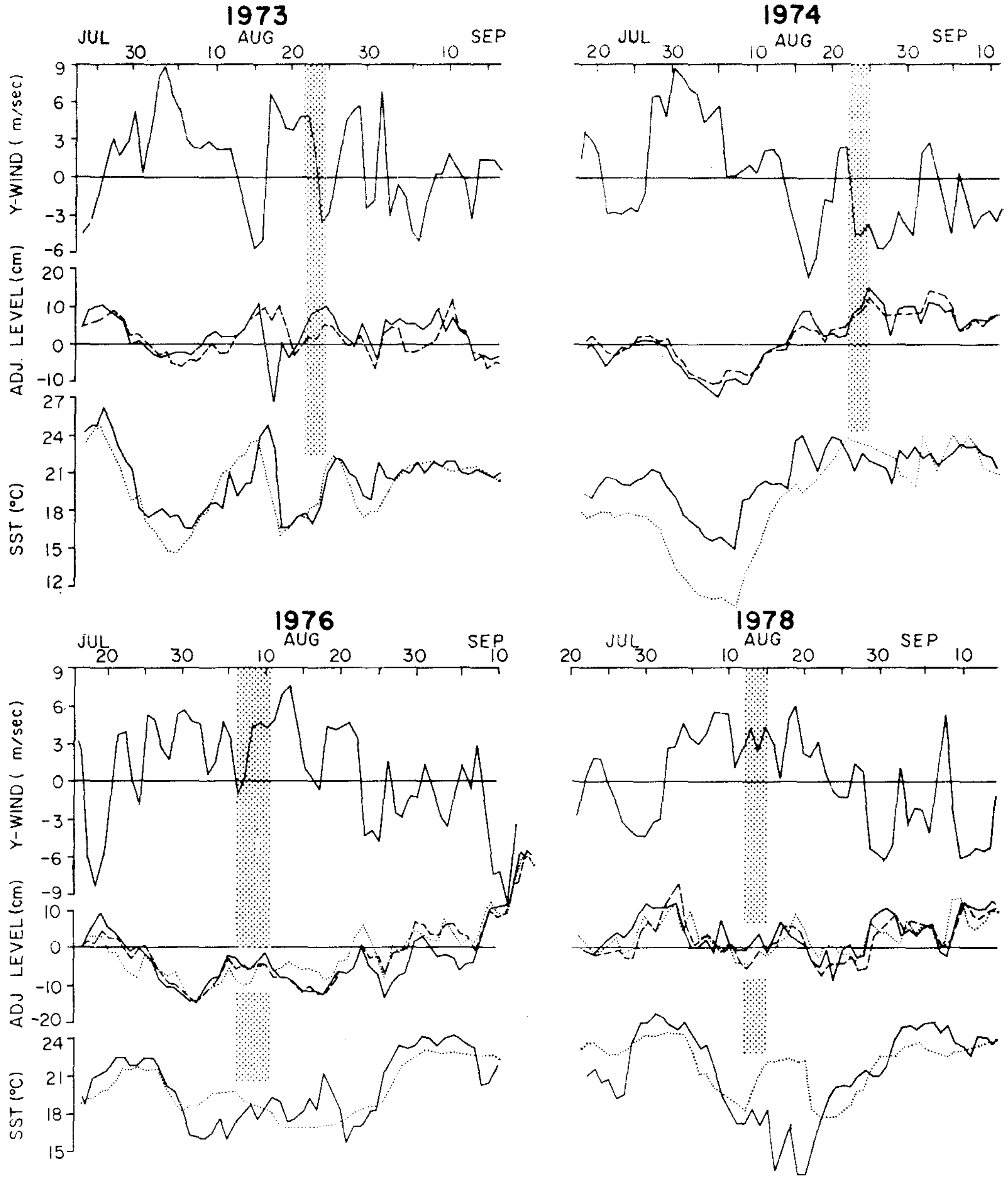

Fig. 3. Daily series of the longshore wind, barometrically adjusted sea level at Pusan (solid line), Ulsan (dashed line) and Pohang (dotted line) and SST at Ulgi (dotted line) and Gampo (solid line).

usually observed in this area of deepest trench. The cold water mass is also located in the trench. Off Ulgi and Gampo, however, isotherms slope upward toward the coast and their steep inclination is confined to about 30km from the coast. Reference layers of cold water, reaching the depths of about 40m and 20m at the coast of Ulgi and Gampo respectively, are shallow enough for SST to respond rapidly to short period upwelling. Strong stratification of temperature in this region results in probably the greatest density change (Fig. 5) from surface to bottom (larger than 4.5 sigma-t unit) at mid-shelf compared with those off Oregon (2.0), NW Africa (0.3) and Peru (0.5) (Smith, 1981). Great density contrast in vertical also yields a

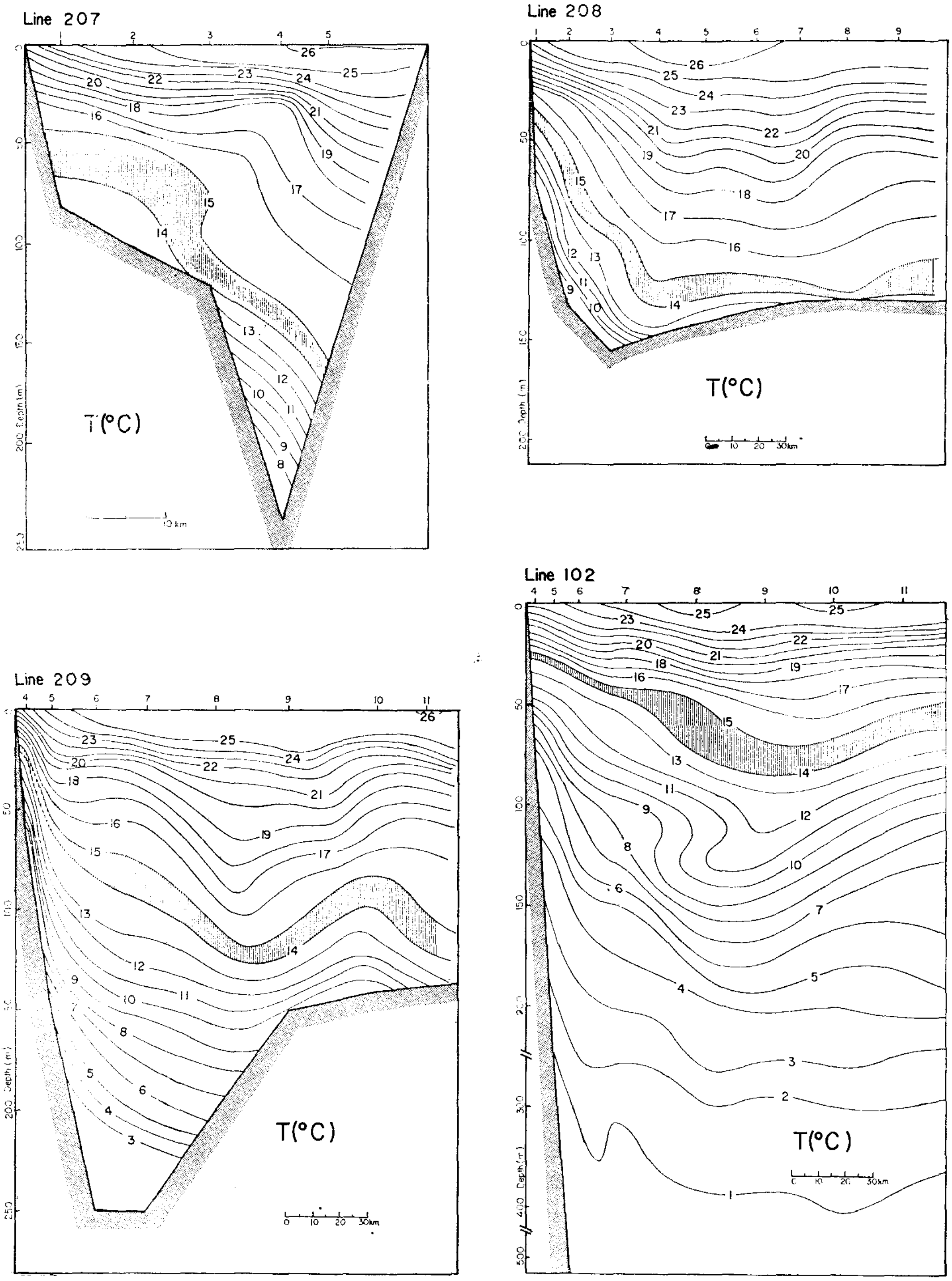

Fig. 4. Vertical sections of mean temperature in August off Pusan (Line 207), Ulsan (Line 208), Gampo (Line 209) and Pohang (Line 102). Arbitrary reference layer between the isotherms of 14 and 15°C are hatched.

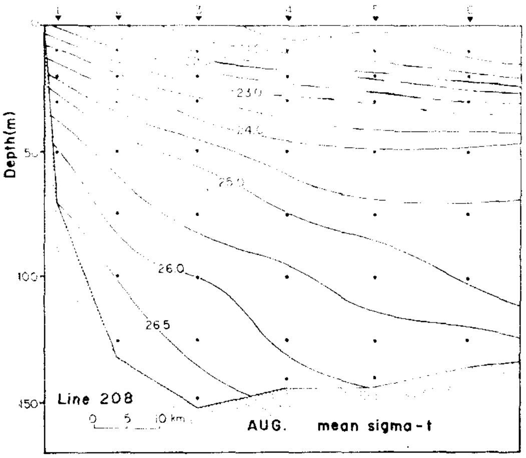

Fig. 5. Vertical section of density of density off Ulsan in August.

large baroclinic Rossby radius of deformation of 20~30km. The steepness is greatest off Gampo and more or less reduced off Pohang. Consequently, the current is considered very strong near the coast of Ulgi to Gampo. This coastal current is called the East Korea Warm Current (EKWC), which is a main branch of the Tsushima Current. The trend of sloping isotherms in mean field does not change substantially even in winter although their steepness and stratification become fairly weak. Thus, this feature is not transient but permanent except February when the Tsushima Current is weakest and the eroding process of stratification is culminated. Numerical experiments by Yoon (1982a,b) on the circulation in the Japan Sea have demonstrated that EKWC, as a predominant western boundary current, always flows along the east coast of Korea regardless of season and bottom topography. Therefore, due to the baroclinic tilting of EKWC, uplifted cold water mass is usually waiting for upwelling at the subsurface layer off the Ulgi-Gampo coast.

It should be noted that the baroclinic tilting of isotherms due to the strong EKWC causes the coldest bottom water to be concentrated in the shallow region near the coast of Ulgi (Line 208 in Fig. 4) whereas this is not the case off Pusan. As a result, the coldest bottom water always exists beneath the strong surface current, and is known to form an undercurrent flowing southward (Byun and Seung, 1984). Both of the tilting of isotherms and the coastward trapping of coldest bottom water off Ulgi may be understood as the results of geostrophic internal adjustment of mass field to the strong western boundary current. In summer, this coastal current is also accelerated by the southerly wind significantly. Horizontal distribution of mean bottom water temperatures (Fig. 6) shows that, from April (not shown here) through December, the axis of cold water (shaded part in Fig. 6) is located on the gentle bottom slope with spreading isobaths off Ulgi to Gampo (stippled area in Fig. 1), while it is in the trench off Pusan. Only in February, the axis of cold water lies in the elongated trough region because the Tsushima Current is too weak to cause the baroclinic tilting. Bottom temperature at the trench off Pusan is rather higher in February than in summer months, and it is lowest (less than 6°C) in July and August. This result indicates that the southward intrusion of undercurrent is most active in summer and weakest in February (Lim and Chang, 1969). As a consequence, we may conjecture that the undercurrent would be closely related with the strength of the Tsushima Current and its main branch (EKWC).

Undercurrents are usually found in the upwelling region, but their dynamical relation to coastal upwelling is not well understood (Smith, 1981). Yoon and Philander (1982) shows numerically that the barotropic and baroclinic Kelvin waves associated with wind-induced coastal jet accelerate the undercurrent. However, undercurrent in the present study is not always related with steady southerly winds favorable for upwelling, becaused the southerly monsoon is prevailing only in summer from june through

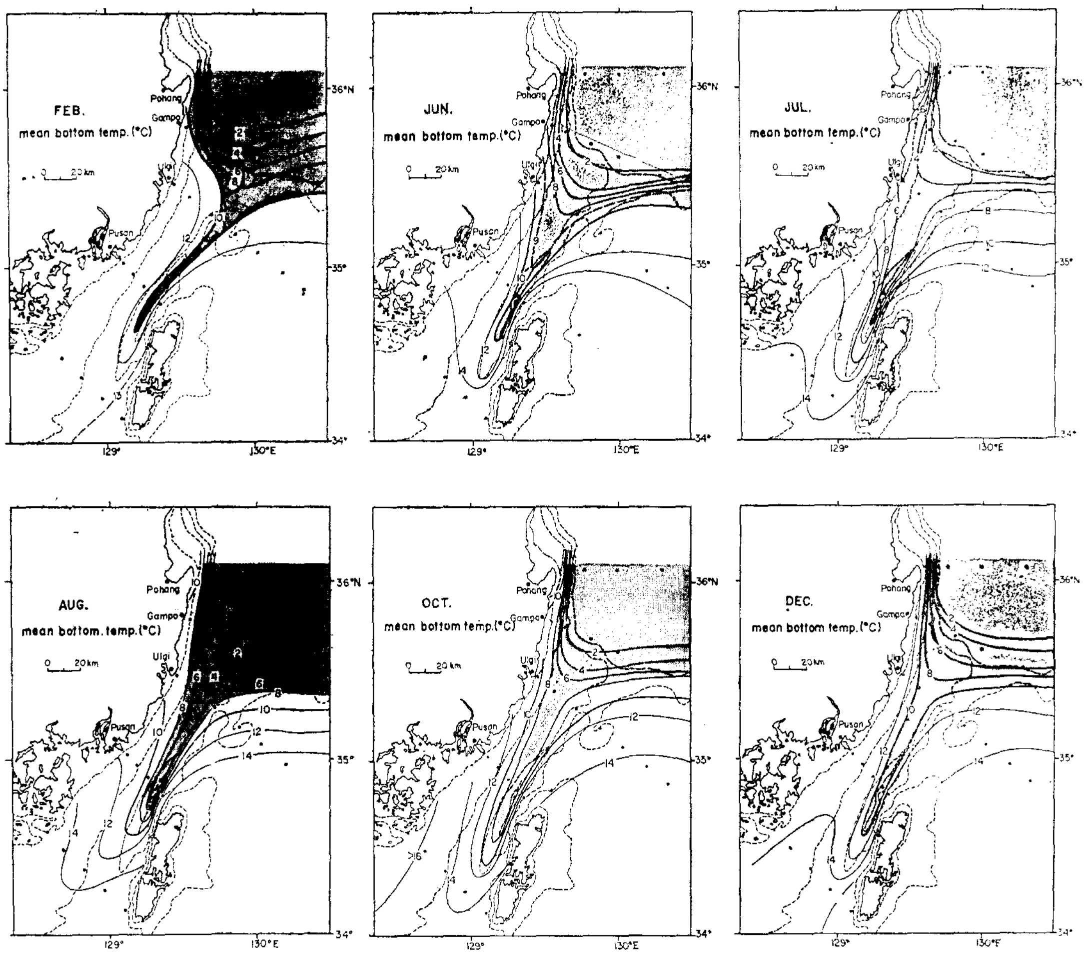

Fig. 6. Horizontal distribution of mean bottom water temperature. Centers of cold water are shaded.

August but the undercurent still seems to occur seasons. The cause of undercurrent related to EKWC may be explained in another way. Development of surface coastal current brings about the tilting of isopycnals of not only the upper layer but also the lower cold layer which is originally horizontal if there is no motion in the upper layer. Tilting of isopycnals requires the baroclinic compensation (Pond and Pickard, 1978, p. 93), i.e., the decrease of longshore flow in vertical. At the lower limit of surface current corresponding approximately to the layer of no motion, the offshore pressure gradient changes sign, thus the undercurrent occurs. Therefore, as the EKWC is intensified in summer, tilting of isopycnals and undercurrent become strong.

Of the whole southeast coast, minimum bottom water temperature is found at the Ulgi-Gampo coast from July to October (Fig. 6); even the bottom temperature north of Gampo is higher than 10°C. This result and mean temperature section (Fig. 4) suggest that EKWC which is strongest off Gampo becomes rather weak afterwards. But it seems difficult to explain why EKWC undergoes such a change. For EKWC flowing northward along the southeast coast, bottom depth increases very abruptly off Gampo (Fig. 1). Two ways of adjustment by EKWC to the rapid increase of depth are possible in order to conserve the potential vorticity. One is to

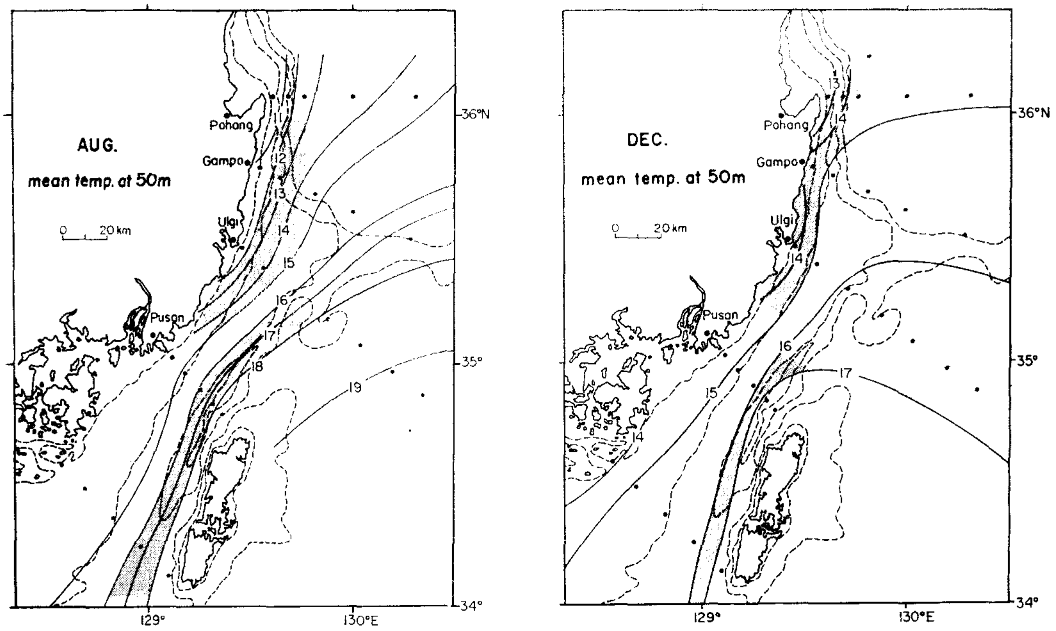

Fig. 7. Mean temperatures at 50m depth. Regions of strong temperature gradient are stippled.

continue following the isobaths along the Korean coast; this is the primaro characteristic of EKWC which is controlled by the planetary beta effect. The other way is to follow the isobaths after the eastward deflection; then the current is controlled by the topographic beta effect which is the generating mechanism of the nearshore branch of Tsushima Current flowing along the Japanese coast (Kawabe, 1982). If the two effects exert simultaneously, EKWC should become weak because of the spreading of current. This phenomenon is shown in dynamic topographies (Fig. 10).

Fig. 7 shows the distributions of mean temperature at 50m depth in August and December. Two figures commonly illustrate that the maximum temperature gradient (shaded areas) associated with strong current appears at the trench region in the strait, and also near the coast of Ulgi to Gampo. Tsushima Cuirent flowing over the trench may be deflected westward to some extent in order to conserve the potential vorticity. If so, the approach of Tsushima Current to the coast south of Ulgi would definitely be favorable for the development of EKWC. Therefore, SST decrease during the wnid-induced upwelling in summer is particularly outstanding only near Ulgi and Gampo because the coastal current is weak elsewhere.

There is another topographic condition favorable for upwelling, that is the diverging bathymetry off the southeast coast as depicted by the stippled area in Fig. 1. Distance between the isobaths of 100 and 150m is about three times larger off Gampo than that off Pusan. Becausethe low-frequency current tends to follow the isobaths, horizontal spreading of surface current is compensated by the up-welling of cold water like the case of the topographically-induced upwelling in the South Atlantic Bight shelf (Blanton et al., 1981). Leming and Moores (1981) also found a shortlived pool of cold upwelled water trapped along the diverging bathymetry between 20 and 50m depths off the Cape Canaveral and suggested the influence of relative vorticity change of the

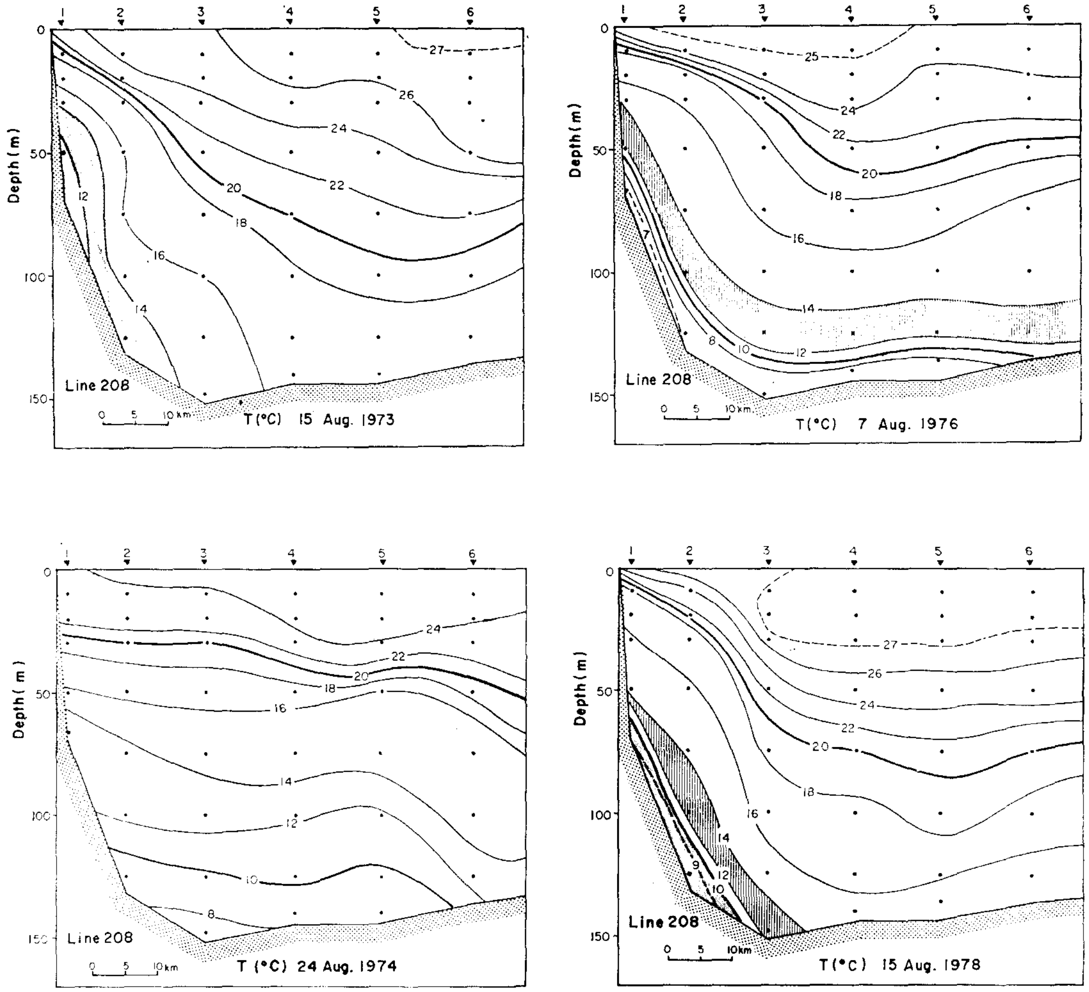

Fig. 8. Vertical sections of temperature off Ulsan in August. Stippled areas represent the wastward trapping of the cold bottom water. Hatched areas are the arbitrary reference layers to be compared with those off Gampo in Fig. 9.

cyclonically curved streamlines along the cape. Theoretical model of the topographically induced upwelling by Janowitz and Pietrafesa (1982) confirms that in the cyclonic region of current, if the isobaths diverge in the downstream direction, then upwelling and onshore flow occur under both of barotropic conditions. It is remarkable that not only the coastline but also the diverging bathymetry has a cyclonic curvature for EKWC. and moreover, the axis of cold water trapped coastward is usually over this diverging isobaths off Ulgi to Gampo except February.

As mentioned previously, among the data sets available, only three cases in 1973, and a case in 1974 are suitable for the description of upwelling and downwelling events, respectively. Periods of hydrographic survey off the southeast coast are indicated by the shaded bars in Fig. 3 showing the inverse correlations of SST and sea level to the variations in longshore wind. Fig.

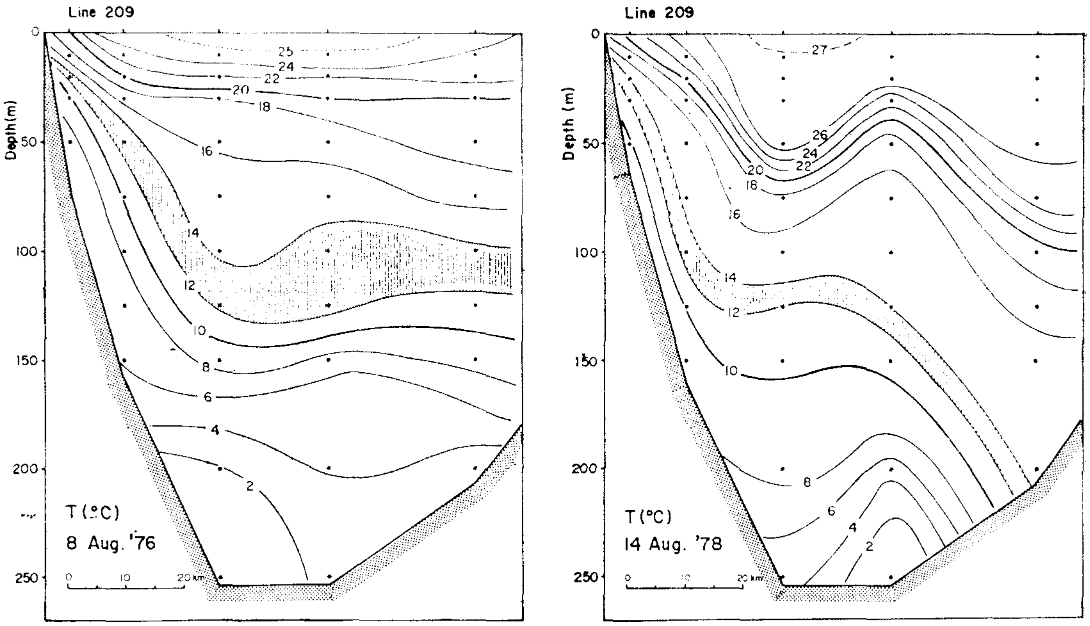

Fig. 9. Vertical sections of temperature off Gampo in August of 1976 and 1978.

8 shows four temperature sections off Ulgi. Coastward trapping of cold bottom water (shaded area) is more apparent at individual upwellings compared to the mean temperature distributions (Fig. 4). Very flat isotherms in August 1974 are closely related to the weak EKWC suppressed by the strong northerly winds which persisted for more than two weeks. SST's and sea levels began to increase at the relaxation period of upwelling, and the maximum values were maintained during the entire downwelling event (Fig. 3).

Hatched areas in Fig. 8 represent the reference layer whose slope and depth are to be compared with those off Gampo (Fig. 9) during the same periods. As shown in mean temperature sections of Fig. 4, slope of isotherms is greater and depth of reference layer is much shallower near Gampo than off Ulgi. Isotherm of 14°C is very close to the sea surface in both cases of 1976 and 1978 so that the decrease in SST during upwelling is more effective at Gampo as also shown in Fig. 3. However, the fact that SST decrease at Ulgi was very great during the upwelling in August of 1974 suggests the importance of initial state of EKWC determined by the fluctuation of Tsushima Current before the coastal jet is accelerated by the upwelling-favorable wind.

In order to examine the gross feature of surface current from hydrographic data, dynamic topographies (Fig. 10) corresponding to four examples above are used. Because our primary interest is in the coastal phenomena, we assumed the 75 decibar surface as a reference level for dynamic topography at the expence of the accurate estimation of surface current in the offshore region. There is an observational evidence of August 1981 that the reference level at about 80m depth was adequate for the dynamic calculation off Ulgi (Byun and Seung, 1984). In fact, dynamic topographies with deeper reference levels were not greately different from those we adopted. During the upwelling periods, with a strengthening effect by the persistent southerly winds, EKWC is generally strong whereas the current during downwelling in August 1974 is quite weak. It

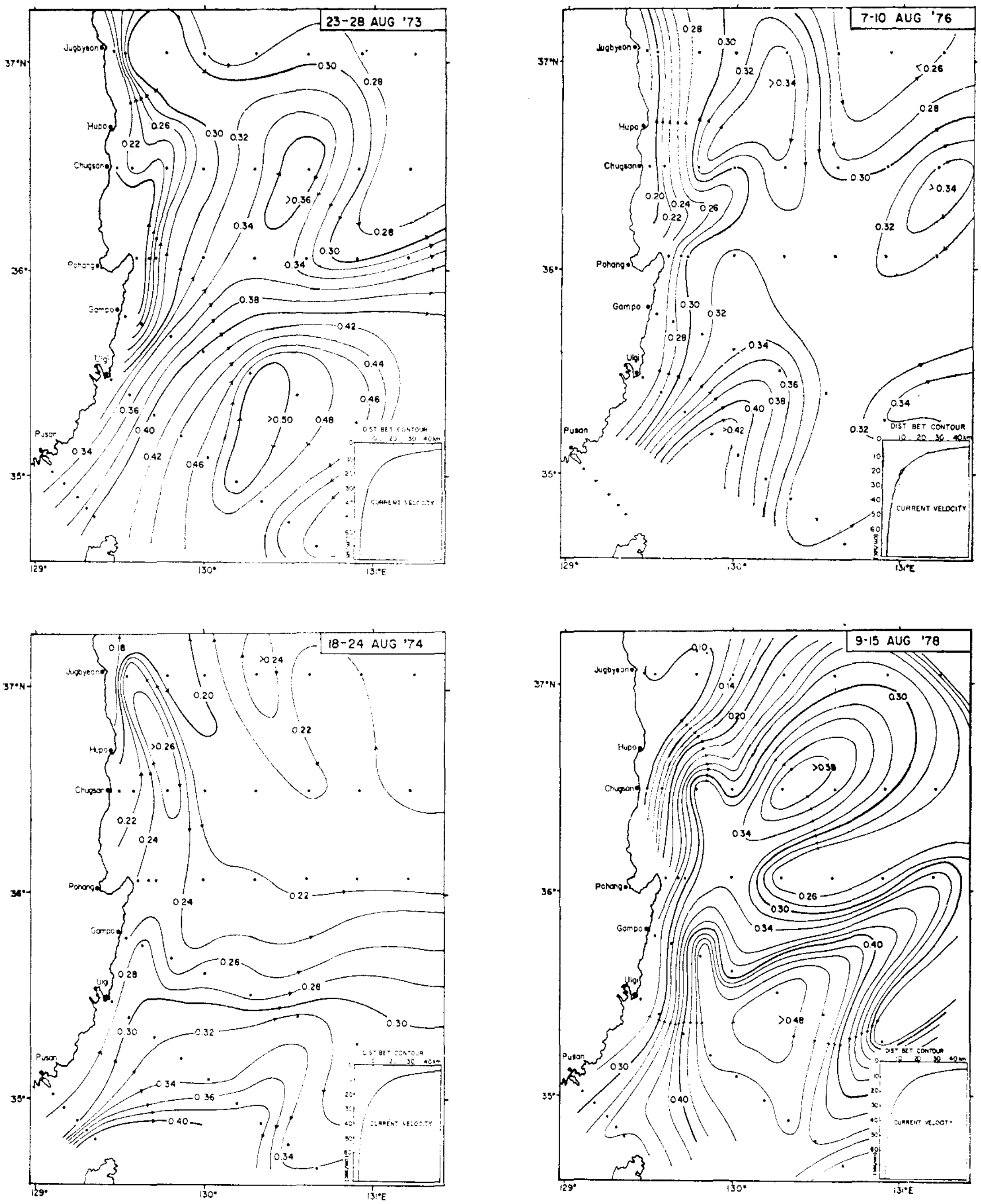

Fig. 10. Dynamic topographies of sea surface in dynamic meters referred to 75 decibar surface in August.

should be noted that the cyclonic curvature of strong EKWC along the diverging bathymetry around Ulgi-Gampo is commonly associated with enhanced upwelilngs in 1976 and 1978. EKWC is usually separated into two branches near the region of abrupt depth increase which may be related with the two ways of adjustment by EKWC. Intensification of EKWC off Gampo is very noticeable, and is responsible for the prominent decrease in SST during upwelling there.

As discussed earlier, although the offshore Ekman transport by the southerly summer monsoon finally induces the coastal upwelling, regional difference in the upwelling intensity represented by SST change at the coast is caused by the variations in the structure of EKWC itself which is very susceptible to bottom topography and initial state of the fluctuating Tsushima Current.

SUMMARY AND CONCLUSIONS

In the first place we examined the mean hydrographic conditions associated with the regional difference in the intensity of wind-induced upwelling represented by the magnitude of SST decrease at the coast. Despite that the actual current or hydrographic fields may have considerable space-time variability, mean hydrographic data reveals the following facts. Isolated deep trench in the Korea Strait can cause the Tsushima Current to deflect westward to some degree even in the stratified condition, thus it favors the development of the western boundary current (EKWC) south of Ulsan. EKWC is particularly strong off the coast of Ulgi to Gampo, but it becomes rather weak afterwards along its way north probably due to the abrupt increase in water depth. Geostrophic internal adjustment of mass field in the strong coastal current regime requires the baroclinic tilting of isotherms and results in the shoaling of cold water toward the subsurface layer near the coast except February when the Tsushima Current is quite weak. Furthermore, tilting effect causes the coldest bottom water to be trapped westward in the shallower shelf region off the Ulgi-Gampo coast. It has been known that the cold water mass flows southward and this uddercurrent is strongest in summer. A schematic diagram of the currents (Fig. 11) illustrates the above results.

If we assume that the longshore wind and its Ekman transport are nearly the same over the whole southeast coast, then the magnitude of SST decrease during the wind-induced upwelling primarily depends on whether there exists the cold water close to the surface or not. In this respect, regional difference in upwelling effect is mainly attributed to the difference in the structure of coastal current whose variability is closely related to the initial state of the Tsushima Current in the Korea Strait and the bottom topography around the southeast coast.

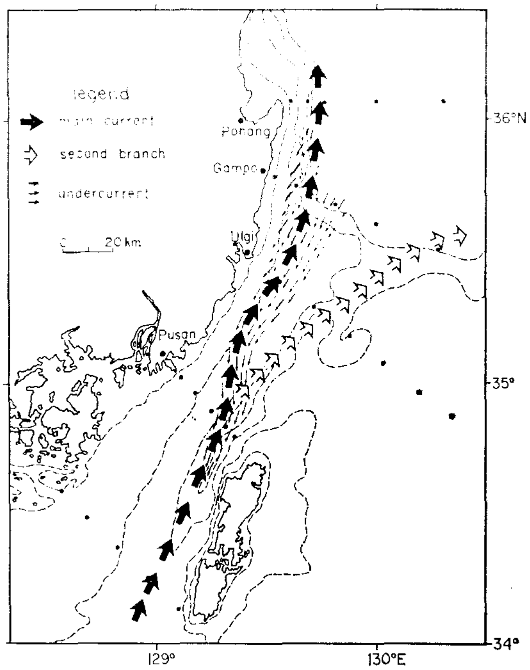

Fig. 11. Schematic diagram of the surface current and undercurrent in summer.

There is a strong possibility that the diverging bathymetry from Pusan to Gampo can favor the upwelling of cold water. It is very remarkable that the axis of cold bottom water is usually located in this region of spreading isobaths off the Ulgi-Gampo coast except February.

Finally, four case studies of upwelling and downwelling events suggest the following facts. Baroclinic tilting effect and westward trapping of the cold bottom water are much more prominent in the individual upwelling than in the mean condition. Surface current and internal structure of mass are considerably susceptible to the variations in wind; strong southerly wind accelerates the Tsushima Current system but northerly wind suppresses it. Wind-induced upwelling is especially enhanced when the EKWC has a cyclonic curvature around the southeast coast.

ACKNOWLEDGEMENTS

We have benbfited from the advices of Drs. Yong Q. Kang, S.D. Chang, and K.D. Cho, National Fisheries University of Pusan, and Dr. H.J. Lie, Korea Ocean Research and Development Institute. Helpful references from Dr. Pietrafesa, North Carolina State University, are gratefully acknowledged.

REFERENCES

An, H.S., 1974. On the cold water mass around the southeast coast of Korean Peninsula. J. Oceanol. Soc. Korea, 9:10-18.

Arthur, R.S., 1965. On the calculation of vertical motion in eastern boundary currents from determination of horizontal motion. J. Geophys. Res., 70: 2799-2803.

Blanton, J.O., L.P. Atkinson, L.J. Pietrafesa and T. N. Lee, 1981. The intrusion of Gulf Stream Water across the continental shelf due to topographically-induced upwelling. Deep Sea Res., 28:393-405.

Byun, S.K. and Y.H. Seung, 1984. Description of current structure and coastal upwelling in the southwest Japan Sea—summer 1981 and spring 1982. *Ocean Hydrodynamics of the Japan and East China Seas*, Elsevier Science Publishers, Amsterdam, pp. 83-93.

Freeman, H.J. and K.L. Denman, 1982. A topographically controlled upwelling center off southern Vancouver Island. J. Mar. Res., 40:1069-1093.

FRDA, 1979. *Oceanographic Handbook of the Neighbouring Seas of Korea*, 3rd ed., Fisheries Research Development Agency, 650pp.

Halpern, D., 1976. Structure of a coastal upwelling event observed off Oregon during July 1973. Deep Sea Res., 23:495-508.

Halpern, D., 1977. Description of wind and of upper ocean current and temperature variations on the continental shelf off Northwest Africa during March and April 1974. J. Phys. Oceanogr., 7:422-430.

Janowitz, G.S. and L.J. Pietrafesa, 1982. The effects of alongshore variation in bottom topography on a boundary current—(topographically induced upwelling). Continental Shelf Res., 1:123-141.

Johnson, D.R., T. Fonseca and H. Sievers, 1980. Upwelling in the Humboldt Coastal Current near Valparaiso, Chile. J. Mar. Res., 38:1-16.

Kawabe, M., 1982. Branching of the Tsushima Current in the Japan Sea, Part II. Numerical Experiment. J. Oceanogr. Soc. Japan, 38:183-192.

Lee, C.K., 1970. On the currents in the Western Channel of the Korea Strait. Bull. Fish. Res. Dev. Agency, 6:175-232.

Lee, C.K., 1974. A study on the currents in the Western Channel of the Korea Strait. Bull. Fish. Res. Dev. Agency, 12:37-106.

Lee, T.N., L.P. Atkinson and R. Legekis, 1981. Observations of a Gulf Stream frontal eddy on the Georgia continental shelf, April 1977. Deep Sea Res., 28:347-378.

Lee, J.C., 1983. Variations of sea level and sea surface temperature associated with wind-induced upwelling in the southeast coast of Korea in summer. J. Oceanol. Soc. Korea, 18:149-160.

Leming, T.D. and C N.K. Mooers, 1981. Cold water intrusions and upwelling near Cape Canaveral, Florida. *Costal Upwelling*, ed. F.A. Richard, American Geophysical Union, 529pp.

Lim, D.B. and S.D. Chang, 1969. On the cold water mass in the Korea Strait. J. Oceanol. Soc. Korea, 4:71-82.

Peffley, M.B. and J.J. O'Brien, 1976. A three-dimensional simulation of coastal upwelling off Oregon. J. Phys. Oceanogr., 6:164-180.

Pond, S. and G.L. Pickard, 1978. *Introductory dynamic oceanography*. Pergamon Press, 241pp.

Seung, Y.H., 1974. A dynamic consideration on the temperature distribution in the east coast of Korea in August. J. Oceanol. Soc. Korea, 9:23-33.

Smith, R.L., 1981. A comparison of the structure and variability of the flow field in three coastal upwelling regions: Oregon, Northwest Africa and Peru. *Coastal*

Upwelling, ed. F.A. Richard, American Geophysical Union, 529pp.

Yoon, J.H., 1982a. Numerical experiment on the circulation in the Japan Sea, Part I. Formation of the East Korean Warm Current. J. Oceanogr. Soc. Japan, 38:43-51.

Yoon, J.H., 1982b. Numerical experiment on the circulation in the Japan Sea, Part II. Influence of seasonal variations in atmospheric conditions on the Tsushima Current. J. Oceanogr. Soc. Japan, 38:81-94.

Yoon, J.H. and S.G.H. Philander, 1982. The generation of coastal undercurrents. J. Oceanogr. Soc. Japan, 38:215-224.

Received 1 August, 1985