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On the Annual Variation of Mean Sea Level along the Coast of Korea

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韓國沿岸 平均 海面의 年變化

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Abstract: The mean sea level (MSL) along the coast of Korea is high in summer and low in winter, mainly due to the inverse barometric effect and the steric departure. The MSL associated with the inverse barometric effect is spatially uniform and has an amplitude of 8.5±0.8cm. The thermal departure, with amplitude of 4~8cm, is most dominant in the Yellow Sea. The MSL in the South Sea of Korea is strongly affected by the haline departure, which has an amplitude up to 5cm. The annual range of MSL along the western and eastern coasts of Korea are about 40 and 20cm, respectively. The spatial inhomogeneity of the annual range of MSL arises mainly due to the influence of the Asian monsoon, which amplifies (weakens) the annual MSL along the western (eastern) coast of Korea.

要約: 한국연안 평균해면은, 주로 대기압과 해수밀도 변화로 인하여, 여름에 높고 겨울에 낮다. 대기압 변화에 수반된 평균해면의 변위는 한국연안 어디에서나 거의 균일하며, 연주기 진폭은 8.5±0.8cm이다. 수온 변화에 따른 해면변위는 연주기 진폭이 4~8cm정도이며, 황해에서 현저하다. 남해의 해면은 염분변화의 영향을 크게 받으며, 이의 연주기 진폭은 5cm까지 이른다. 월별 평균 해면의 연교차는 서해에서 40cm 정도이고 동해에서 20cm 정도인데, 이와 같은 지역에 따라 연교차가 다른 주원인은 계절풍이 서해에서는 해면의 연교차를 증가시키나, 동해에서는 감소시키기 때문이다.

INTRODUCTION

The mean sea level (MSL) along the coast of Korea shows a pronounced annual variation. It is high in summer and in winter everywhere along the coast of Korea. The annual range, however, is not uniform. The annual range of MSL in the western coast (about 40cm) is approximately twice as large as that in the eastern coast (about 20 cm).

The annual variations of MSL are caused by the combined effects of the atmospheric pressure change (inverse barometric effect), the steric departure of sea level associated with the changes in temperature and salinity, the variation of wind stress, and by the fresh water exchange associated with evaporation, precipitation and river run-off. The relative importance of each factor mentioned above on the annual variation of MSL differs from place to place. The variations of MSL along the coast of Korea is produced mainly by the steric departure and the inverse barometric effect (Yi, 1967). Along the Japanese coast, the variations of MSL are chiefly produced by the variation of sea water temperature and secondly by the variation of the

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atmospheric pressure (Nomitsu and Okamoto 1927). In the South China Sea, on the other hand, the variations of MSL are caused mainly by the monsoon winds, and the variation of atmospheric pressure is not important (Tvi, 1970).

The annual variation of MSL along the coast of Korea was studied by Yi (1967) based on the sea level data up to 6 years (1962~1967). The same problem is reexamined in this paper by using the sea level records for 19 years (1965~1983) at 7 tidal stations in Korea. An emphasis is placed in explaining why the annual range of MSL along the western coast is much larger than that along the eastern coast. In this paper it will be shown that the residual MSL, that is, the MSL corrected for the inverse barometric effect and the steric departure, in the western coast is almost out of phase from that in the eastern coast. A simple model for the effect of winds on the sea level variation along the coast is developed in this paper in order to understand the spatial inhomogeneity in the annual range of MSL along the coast of Korea.

DATA AND ANALYSIS

The monthly normals of MSL at 7 stations (Inchon, Mokpo, Cheju, Yosu, Pusan, Ulsan, and Mukho), shown in Fig. 1, are based on the MSL for 19 years from January 1965 to December 1983 (Hydrographic Office, Korea, 1965~1983). The monthly normals of atmospheric pressure, which are used in estimating the inverse barometric effect, are based on the monthly normals during the same period (1965~1983) at the locations coinciding with the tide stations, except the atmospheric pressure at Kangreung is used in estimating the inverse barometric effect at Mukho (Central Meterological Office, Korea, 1965~1983). The monthly normals of sea water temperature and salinity over 15 years (1961~1975) at 7 oceanographic stations are used in computing the steric departure of MSL (Fisheries Research and Development Agency, Korea, 1979). Some missing data for the temperature and salinity normals were linearly interpolated. The tidal, meteorological, and oceanographic stations are shown in Fig. 1.

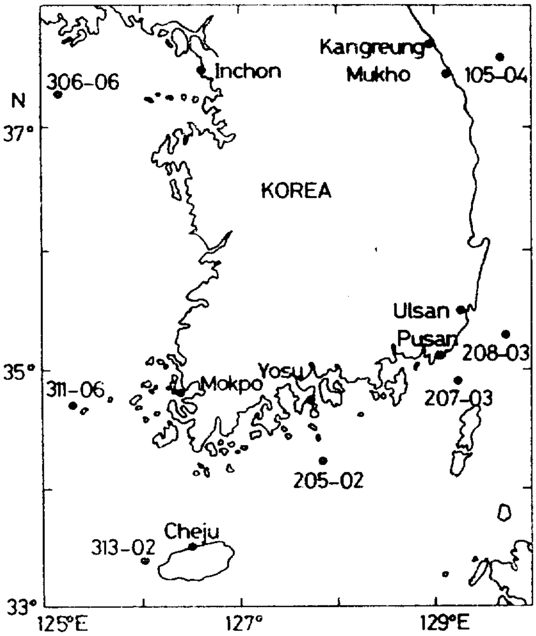

Fig. 1. Tidal, meteorological, and oceanographic stations.

The variations of MSL associated with the atmospheric pressure change is estimated by assuming that the sea level adjusts hydrostatically to the atmospheric pressure. An increase of atmospheric pressure by 1 mb reduces the MSL by 1cm.

The steric departure of sea level, h_{ST}, associated with the change of specific volume by $\Delta\alpha$ is

$$h_{ST}=g^{-1}\int_{p_0}^{p_z}\Delta\alpha\, dp, \qquad (1)$$

where g is the gravity, p_0 the stmospheric pressure, and p_z the pressure at depth z (Pattullo et al, 1955; Lisitzin, 1974). The change of specific volume from the annual mean can be approximated to

$$\Delta\alpha = (\partial\alpha/\partial T)\Delta T + (\partial\alpha/\partial S)\Delta S, \quad (2)$$

where α is the specific volume, and ΔS are the deviations of temperature and salinity from the annual averages, respectively. The steric departure is the sum of thermal and haline departures. The thermal departure of MSL, h_T, associated with the temperature change can be computed by

$$h_T = g^{-1}\int_{p_0}^{p_s}(\partial\alpha/\partial T)\ \Delta T\,dp = -\int_{-z}^{0} e_T\,\Delta T dz, \quad (3)$$

where $e_T = \alpha^{-1}(\partial\alpha/\partial T)$ is the coefficient of thermal expansion. Similarly, the haline departure, h_s, associated with salinity change can be computed by

$$h_s = g^{-1}\int_{p_0}^{p_s}(\partial\alpha/\partial S)\Delta S\,dp = -\int_{-z}^{0} e_s\,\Delta S\,dz, \quad (4)$$

where $e_S = \alpha^{-1}(\partial\alpha/\partial S)$ is the coefficient used in this work are $e_S = 0.75\times10^{-3}(‰)^{-1}$ and $e_T = (0.7+0.0867T)\times10^{-4}(°C)^{-1}$, where sea water temperature T is in Celcius degrees (Gill, 1982).

Since the water temperature and salinity in coastal region vary significantly from day to day, the monthly normals of temperataure and salinity reported by the Fisheries Research and Development Agency (1979), which were based on the hydrocast data with sampling intervals of one or two months over 15 years (1961~1975), may be different from the monthly means computed based on daily data. For example, the high-frequency temperature fluctuations with time scales of days to weeks reach up to 5°C in the eastern coast of Korea (Korea Ocean Research and Development Institute, 1981). If the water temperature in the upper layer of 20m depth were changed by 5°C within a few days, then the thermal departure computed by (3) would be about 1cm. In this paper, due to a lack of continuous daily data at depths, the possible influences of high-frequency fluctuations of temperature and salinity on the monthly MSL are neglected. It should also be noted that the estimates of steric departure can be changed significantly depending on the choice of oceanographic stations and, at the same time, they should be close enough from the coastal station to ensure spatial homogeneity in the steric departure. Table 1 shows

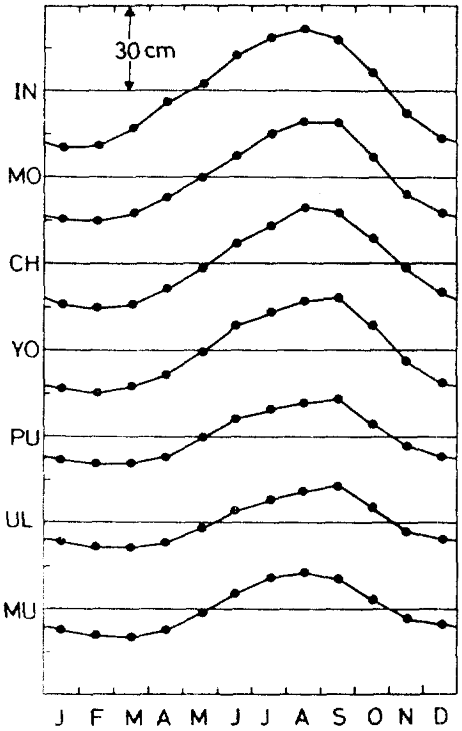

Fig. 2. Annual variations of MSL over 19 years (1965~1983) at Inchon (IN), Mokpo (MO), Cheju (CH), Yosu (YO), Pusan (PU), Ulsan (UL), and Mukho (MU).

Table 1. Oceanographic stations of Fisheries Research and Development Agency (FRDA) and reference depths used in estimating thermal and haline departures of MSL.

FRDA Ocean Station	306-06	311-06	313-02	205-02	207-03	208-03	105-04
Reference Depth (m)	50	75	75	50	100	125	200
Tidal Station	Inchon	Mokpo	Cheju	Yosu	Pusan	Ulsan	Mukho

Table 2. Monthly normals (in cm) of components of sea-level variation from 1965 to 1983 at 7 coastal stations.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Station: Inchon												
Obser.	−19.7	−19.0	−13.1	−3.8	2.2	12.2	18.5	22.0	18.2	6.6	−7.8	−16.1
Press.	−8.0	−6.7	−3.4	0.5	4.9	8.5	10.2	8.7	3.0	−3.0	−6.6	−8.1
Therm.	−5.1	−6.0	−6.2	−4.3	−1.8	1.0	4.6	8.1	6.7	5.4	1.7	−4.1
Haline	−0.4	0.0	−1.2	−0.1	0.8	0.9	0.9	0.9	0.6	0.2	−0.3	−0.7
Resid.	−6.3	−6.3	−2.4	0.1	−0.1	1.8	2.9	4.2	7.9	4.0	−2.7	−3.2
Station: Mokpo												
Obser.	−14.7	−15.3	−12.8	−7.1	−0.3	7.2	14.8	19.4	19.1	7.5	−5.7	−12.3
Press.	−7.7	−6.5	−3.6	0.2	4.5	8.2	9.9	8.7	3.5	−2.7	−6.6	−7.9
Therm.	−4.5	−7.7	−7.6	−6.4	−3.2	0.8	5.9	7.5	9.3	4.8	2.2	−1.2
Haline	0.0	−0.3	−1.1	−0.5	−0.4	−2.2	−0.4	0.2	2.4	−0.2	2.2	0.2
Resid.	−2.5	−0.8	−0.4	−0.4	−1.2	0.3	−0.6	3.0	3.9	5.5	−3.5	−3.4
Station: Cheju												
Obser.	−14.3	−15.5	−14.0	−8.7	−1.9	6.9	12.7	19.6	17.6	9.0	−1.4	−10.0
Press.	−7.6	−6.4	−3.6	0.1	4.4	8.1	9.8	8.6	3.5	−2.6	−6.6	−7.8
Therm.	−2.0	−3.8	−5.7	−4.3	−1.9	0.2	3.0	4.8	5.6	2.8	1.3	−0.1
Haline	−2.9	−4.4	−5.7	−2.9	−2.0	−1.5	1.4	5.0	8.8	4.2	1.4	−1.5
Resid.	−1.9	−1.0	1.0	−1.6	−2.4	0.1	−1.5	1.3	−0.4	4.6	2.5	−0.6
Station: Yosu												
Obser.	−13.4	−15.0	−12.7	−8.4	−0.9	8.3	13.1	17.1	18.5	8.5	−3.7	−11.4
Press.	−6.9	−5.8	−3.1	0.0	4.2	7.6	8.9	8.0	3.2	−2.5	−6.2	−7.4
Therm.	−3.4	−4.2	−4.2	−3.2	−1.3	0.9	1.8	4.2	6.3	4.1	1.8	−2.7
Haline	−0.9	−2.1	−3.0	−2.6	−1.7	−0.4	−0.4	2.6	4.8.	2.8	0.4	0.4
Resid.	−2.2	−2.8	−2.5	−2.5	−1.9	0.1	2.8	2.3	4.2	4.1	0.2	−1.7
Station: Pusan												
Obser.	−8.2	−9.6	−9.4	−7.0	−0.6	6.0	9.2	11.8	13.3	4.4	−3.1	−7.0
Press.	−6.3	−5.3	−2.8	−0.2	4.0	7.3	8.4	7.5	2.8	−2.6	−6.0	−6.8
Therm.	−3.3	−6.2	−6.9	−6.4	−3.0	0.1	2.2	4.0	9.0	6.2	4.4	0.0
Haline	−2.8	−2.7	−3.5	−2.9	−3.1	−0.5	3.0	4.3	6.1	3.0	0.2	−1.1
Resid.	4.2	4.7	3.9	2.5	1.5	−0.9	−4.5	−4.0	−4.6	−2.2	−1.7	1.0
Station: Ulsan												
Obser.	−6.7	−8.7	−8.7	−6.9	−2.1	4.1	8.1	10.8	13.2	5.4	−2.9	−5.5
Press.	−6.3	−5.4	−2.9	−0.1	4.2	7.4	8.7	7.6	2.6	−2.8	−6.2	−6.8
Therm.	−5.1	−6.0	−6.2	−5.3	−3.4	0.4	2.0	3.6	5.1	6.7	7.3	0.8
Haline	−1.9	−2.6	−4.0	−2.5	−3.2	−1.0	1.7	4.4	3.9	3.4	1.7	−0.1
Resid.	6.6	5.2	4.4	0.9	0.4	−2.8	−4.4	−4.8	1.6	−1.8	−5.7	0.5

Station: Mukho

Obser.	−7.3	−9.4	−9.9	−7.4	−1.5	5.4	11.0	13.0	10.8	3.4	−3.2	−4.9
Press.	−6.1	−5.4	−3.0	0.2	4.7	7.4	8.8	7.1	1.5	−3.2	−5.9	−6.2
Therm.	0.4	−2.9	−4.5	−3.0	−4.4	−2.0	0.1	3.0	2.8	4.3	2.5	3.7
Haline	0.0	−0.9	−2.0	−1.5	−0.4	−1.4	−0.1	2.1	2.7	1.2	−0.4	0.8
Resid.	−1.6	−0.2	−0.4	−3.1	−1.4	1.4	2.2	0.8	3.8	1.1	0.7	−3.2

Table 3. Amplitude, A in cm, and phase, ϕ in degrees, of various components of sea-level variations from 1965 to 1983 at 7 coastal stations.

Comp.	Observed		A.P. Adj.		Thermal		Haline		Residual	
Station	A	ϕ	A	ϕ	A	ϕ	A	ϕ	A	ϕ
Inchon	20.7	(211°)	9.2	(186°)	7.0	(237°)	0.7	(221°)	5.3	(220°)
Mokpo	17.5	(220°)	9.0	(245°)	8.1	(245°)	1.2	(297°)	2.3	(229°)
Cheju	17.2	(227°)	8.9	(188°)	4.9	(250°)	5.4	(251°)	1.7	(287°)
Yosu	16.9	(223°)	8.3	(187°)	4.8	(243°)	3.0	(263°)	3.4	(245°)
Pusan	11.4	(224°)	7.1	(187°)	7.0	(259°)	4.3	(247°)	4.6	(57°)
Ulsan	10.4	(230°)	7.9	(186°)	6.5	(262°)	3.9	(259°)	4.2	(48°)
Mukho	11.1	(225°)	7.7	(183°)	4.2	(267°)	1.6	(267°)	2.1	(234°)

the oceanograpic stations and the corresponding reference depths, which are used in computing steric departues of MSL at 7 coastal stations.

The monthly normals of the observed MSL, the inverse barometric effect, and the thermal and haline departures are shown in Table 2. Fig. 2 shows the observed MSL. The MSL is high in summer and low in winter everywhere along the coast of Korea. The annual amplitude of MSL, however, is not uniform but differs from station to station. The annual amplitude of MSL is about 20 cm along the western coast, about 17 cm along the southern coast, and about 10cm along the eastern coast.

Each of those de-averaged normals, h, in Table 2 is harmonically fitted by

$$h=A\cos(\omega t-\phi)+A'\cos(2\omega t-\phi'), \qquad (5)$$

where ω the annual angular speed ($\omega=2\pi\, yr^{-1}$), A and A' the annual and semi-annual amplitudes, respectively, and ϕ and ϕ' the corresponding phases. The amplitudes and phases of annual variation are shown in Table 3. In this table, the annual phases of 210° and 240° represent that the sea level is maximal on August 1 and September 1, respectively. The amplitudes of semi-annual variation are much smaller than the annual ones (typically less than 20%), and the phases vary irregularly. The harmonic constants for semi-annual component are not shown in the table.

The influece of the atmospheric pressure on the MSL is almost uniform and in phase everywhere along the coast of Korea. The annual amplitude of MSL associated with the variation of atmospheric pressure is 8.5 ± 0.8cm, and the corresponding sea level is maximal in early July. The thermal departure of MSL has annual amplitude of 4~8cm, and the maximum occurs at the end of August or in September. The haline departure of MSL at each station is almost in phase with the thermal departure, and the maximum occurs in summer (July to September). The annual amplitude of haline departure is large (4~5cm) at southern coast or in the regions influenced by the Tsushima Current, but it is very small (less than 2cm) along the eastern and northwestern coasts. The effects of the atmospheric pressure and the

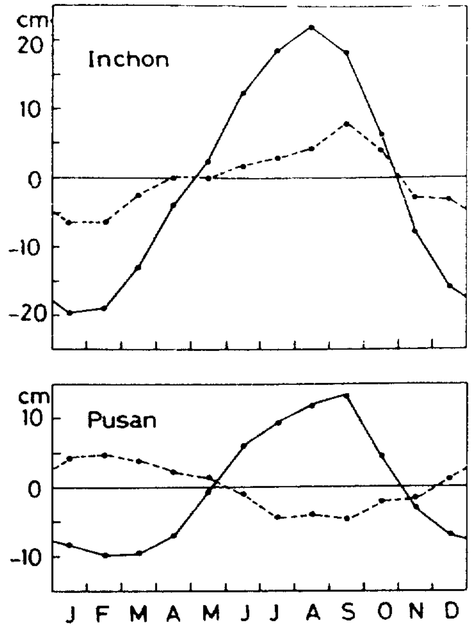

Fig. 3. Annual variations of the observed (solid curve) and the residual (dotted curve) MSL at Inchon and at Pusan.

steric departure of MSL are almost in phase. That is, the variations of both atmospheric pressure and density of sea water cause the MSL in summer to be higher than in winter.

Table 3 also shows that the observed MSL is not completely described by the combination of the inverse barometric effect and the steric departure. Fig. 3 shows the annual variations of the observed MSL and the residual at Inchon and Pusan. The amplitude of residual MSL is about 5 cm at Inchon, and about 4 cm at Pusan and Ulsan. The residuals of MSL at Pusan and Ulsan are almost out of phase from those in other stations. The residual MSL is associated with the seasonally reversing Asian monsoon, as will be shown in the next section.

WIND EFFECT

In order to understand the effect of the Asian monsoon on the sea level variation along the coast of Korea, let's consider a semi-infinite homogeneous ocean of constant depth. The linearized momentum and continuity equations are

$$\partial u/\partial t - fv = -g^{-1}\partial\zeta/\partial x + \tau_x/(\rho H) \qquad (6)$$

$$\partial v/\partial t + fu = -g^{-1}\partial\zeta/\partial y + \tau_y/(\rho H) \qquad (7)$$

$$\partial\zeta/\partial t + H(\partial u/\partial x + \partial v/\partial y) = 0, \qquad (8)$$

where u and v are barotropic velocity components to the x (east) and y (north) directions, respectively, f the Coriolis parameter, ζ the sea level elevation, H the depth of the ocean, ρ the density of sea water, and τ_x and τ_y the wind stress comonents to the x and y-directions, respectively. The bottom friction is neglected in Eqs. (6) and (7).

Suppose there is a meridional coastline with a vertical wall at $x=0$, and the wind blows parallel to the coast. In this case, there is no variation in y (i.e. $\partial/\partial y=0$) and therefore (6), (7) and (8) become

$$\partial u/\partial t - fv = -g^{-1}\partial\zeta/\partial x \qquad (9)$$

$$\partial v/\partial t + fu = \tau_y/(\rho H) \qquad (10)$$

$$\partial\zeta/\partial t + H\partial u/\partial x = 0. \qquad (11)$$

Differenciate (9) with respect to t, multiply (10) by f, and then apply (11) to the sum of them to get an equation with u as a single variable:

$$\partial^2 u/\partial t^2 + f^2 u - gH\partial^2 u/\partial x^2 = f\tau_y/(\rho H). \qquad (12)$$

Consider a seasonally reversing meridional wind stress described by

$$\tau_y(t) = T \cos \omega t, \qquad (13)$$

where T is the amplitude of wind stress. A substitution of (13) into (12) yields that the offshore current should be proportional to $\cos\omega t$, i.e.,

$$u(x,t) = U(x) \cos t\omega t, \qquad (14)$$

and the x-dependent amplitude $U(x)$ should satisfy

$$(f^2-\omega^2)U - gH\, d^2U/dx^2 = fT/(\rho H). \qquad (15)$$

In a western half-plane ocean of depth H_1 (the region I in Fig. 4), there should be no normal flow at the coast ($x=0$) and the flow at infinite from the coast should be the same as the time-dependent Ekman transport without

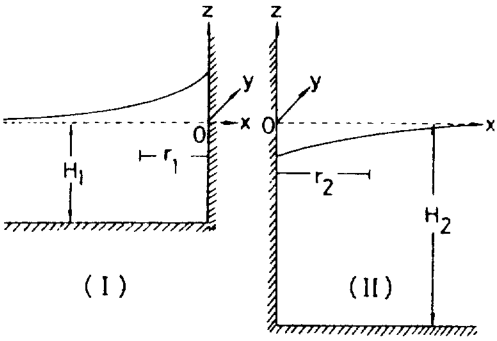

Fig. 4. Schematic diagram showing the sea-level elevations associated with meridional wind stress in the werstern (region I) and eastern (region II) half-plane oceans with with depths H_1 and H_2, respectively.

sea level variation (Kang, 1982). That is,

$$U(x)=0 \text{ at } x=0, \tag{16}$$
$$U(x)=fT[(f^2-\omega^2)H_1]^{-1} \text{ at } x=-\infty.$$

The solution of (15) that satisfies the boundary conditions (16) is

$$U(x)=fT[(f^2-\omega^2)\ \rho H_1]^{-1}[1-\exp(x/r_1)]\cong T(f\rho H_1)^{-1}[1-\exp(x/r_1)], \tag{17}$$

where

$$r_1=[gH_1/(f^2-\omega^2)]^{1/2}\cong(gH_1)^{1/2}/f \tag{18}$$

is the barotropic Rossby radius of deformation, and the condition $\omega\ll f$ is used in (17) and (N.B. $\omega=2\times10^{-7}\ \text{sec}^{-1}$ and $f=10^{-4}\text{sec}^{-1}$). The offshore current in region I is, from (14) and (17),

$$u_1(x,t)=T(f\rho H_1)^{-1}[1-\exp(x/r_1)]\cos\omega t. \tag{19}$$

A substituion of (19) into the continuity equation (11) yields the sea level elevation:

$$\zeta_1(x,t)=T(\rho\omega f r_1)^{-1}\exp(x/r_1)\ \sin\omega t. \tag{20}$$

Similarly, the variations of current and sea level in an eastern half-plane ocean of depth H_1 (the region II in Fig. 4) are

$$u_2(x,t)=T(f\rho H_2)^{-1}[1-\exp(-x/r_2)]\cos\omega t \tag{21}$$
$$\zeta_2(x,t)=-T(\rho\omega f r_2)^{-1}\exp(-x/r_2)\sin\omega t, \tag{22}$$

where

$$r_2=(gH_2)^{1/2}/f. \tag{23}$$

Eqs. (20) and (22) show that the wind-induced sea level elevations are maximal at the cost and decrease exponentially with distance from the coast. The e-folding distance is given by the barotropic Rossby radius of deformation, of wich magnitude is proportional to the square-root of the depth. The amplitude of MSL at the coast is inversely proportional to the radius of deformation or to the square-root of the depth. Eqs. (20) and (22) also show that the sea level elevations, associated with the same wind stress, at the eastern and western half-planes are out of phase each other. Fig. 5 shows schematically the temporal change of sea level variation, associated with seasonally reversing wind, at the coasts of the western and eastern half-plane oceans.

Since the West Sea (Yellow Sea) is shallower than the East Sea (Japan Sea), the above results suggest that the wind-induced sea level variation at the western coast of Korea has a larger ampitude than in the eastern coast. The

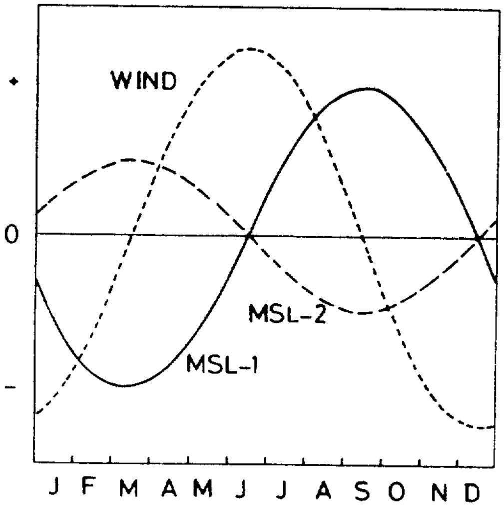

Fig. 5. Schematic diagram showing the phase relations among the wind stress (WIND), MSL along western coast (MSL-1), and MSL along eastern coast (MSL-2).

corresponding phases, associated with the Asian monsoon, along the eastern and western coasts should be opposite each other.

For the sake of an illustration, let's assume that the horizontally uniform alongshore wind, W, is given by $W=0.4\cos\omega t$ (m/sec). In this case, the amplitude of wind stress computed by $T=c_D\rho_a W^2$, where c_D is the drag coefficient ($c_D=1.1\times10^{-3}$) and ρ_a the density of air ($\rho_a=1.3\times10^{-3}$g/cm^3) would be 2.3×10^{-3}dyn/cm^2. The amplitude of sea level elevation at the coast of an semi-infinite ocean of 40m depth would be 6cm. The corresponding amplitudes in 100m and 1,000m oceans would be 4cm and 1cm, respectively.

DICUSSION AND CONCLUSIONS

In this paper I described the spatio-temporal characteristics of the annual variation of MSL along the coast of Korea and then discussed the physical mechanisms involved. The observed MSL is decomposed into the inverse barometric effect, the steric (thermal and haline) departure, and the residual. Since the estimates for the steric departure of MSL depend on the choice of the oceanographic stations and the refernce depths, the 'true' residuals of MSL at the tidal stations may be somewhat different from the values presented in this paper. It was shown, however, that the observed MSL is not fully described merely by a superposition of inverse barometric effect and steric departure. The residual of MSL along the western coast is almost out of phase from that along the eastern coast. In this paper, by means of analytic modelling for the effect of seasonal wind on coastal MSL, it was shown that a major part of the residual is associated with the Asian monsoon which is southeasterly in summer and northwesterly in winter.

Since many simplifying assumptions are used in the model, the analytic results may be somewhat different from the actual sea level variations associated with the seasonal winds along the coast of Korea. The actual ocean is quite different from a semi-infinite ocean of uniform uniform depth. Effects of complicated coastal geometry, bottom topography, and density stratification are neglected in the model. Besides, the actual wind field is not precisely described by a sinusoid with an annul cycle. In spite of these simplifications and limitations, the model gives us the first order explanation for the fact that the annual variations of residual MSL along the eastern and western coasts are almost opposite each other.

The annual variation of MSL along the coast of Korea can be summerized as follows. The MSL is high in summer and low in winter due to the superposition of the inverse barometric effect and the steric departure. The inverse barometric effect has an amplitude of 8.5±0.8 cm and it is almost uniform along the coast of Korea. The thermal departure has an amplitude of 4~8cm and this effect is most dominent in the Yellow Sea, where the annual range to temperatue is large (Kang and Jin, 1984a). The haline departure has a widely varying amplitude between 1 to 5cm, and is most significant in the South Sea of Korea or in the regions of Tsushima Current, where the annual variation of salinity is large mainly due to the seasonal discharge of fresh water from the Yangtze River (Kang and Jin, 1984b). Along the western coast of Korea, the influences of the Asian monsoon on the annual variation of MSL are almost in phase with those associated with inverse barometric effect and steric departure and, therefore, the annual range of MSL is large. Along the eastern coast, on the other hand, the MSL associated with the seasonal wind is almost out of phase from other factors and, therefore, the annual range of MSL is small.

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