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대한해협 주변해역 조석현상 연구

A Study on the Tidal Phenomena in the Seas Adjacent to the Korea Strait

1993. 6.

한국해양연구소

제 출 문

한국해양연구소장 귀하

본 보고서를 "대한해협 주변해역 조석현상 연구" 사업의 최종보고서로 제출합니다.

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연구책임자 : 강석구(연안공학연구실)
염기대(연안공학연구실)
연 구 원 : 이상룡(부산대학교)
연구 조원 : 김용권(연안공학연구실)
송한준(")
백원대(")
김윤칠(")
김미경(")

요 약 문

Ⅰ. 제목

대한해협 주변해역 조석현상 연구

Ⅱ. 연구개발의 목적 및 중요성

한반도 주변해인 동지나해, 황해, 남해, 동해의 조석현상은 1900년대 초반부터 시작되어 1930년대에는 일본의 Ogura(1933)에 의하여 주요분조에 대한 조석도(Tidal charts)가 작성되기에 이르렀다. 이후 1970년대 후반이후에는 수치모델링이라는 새로운 연구기법,해석해법(Analytical solution method) 및 추가적인 현장관측자료에 입각한 분석 등을 통하여 한반도 주변해에서의 조석현상 연구가 활발하여 왔다(An(1977), Nishida(1980), Choi(1980, 1988), Kang(1984), Fang(1986), Odamaki(1989), Kang(1988, 1981)). 이들 연구중 Odamakil는 최근 관측자료를 이용하여 분석한 결과,고전적으로 통용되어 오던 Ogura 조석도의 몇가지 부정확성(Inaccuracy)을 지적하였으며, Kang(1991)은 수치모델링과 해석적 방법에 근거하여 Ogura 등에 의한 조석도의 재작성 혹은 부분적 수정의 필요성과 함께 이를 위해 광범위하고 정밀한 현장관측이 필요함을 주장하였다.

본 연구는 기존 일본학자 및 중국학자들에 의해서 작성된 조석도에 대한 재검토와 본 연구의 연구진 일원이 제창한 조석도 변화의 가설을 확인하기 위한 연구의 필요성에 의하여 실시하며 일차적으로 한반도 주변 조석의 구조적 특성 파악의 필요성이 제기되었다. 아울러 기초적 이론을 뒷받침하고 현상규명에 대한 유효한 자료를 수집할 목적으로 대한해협 일대를 대상으로 한 현장관측이 필요한 것으로 판단된다. 현장관측과 이론적 고찰외에도 수치실험을 통한 현상의 정량적 특성에 관한 연구도 현상을 규명하는 데 유용할 것이다.

Ⅲ. 연구개발의 내용 및 결과

1. 현장관측, 자료수집 및 분석

- 조석 : 6개 지점의 1개월 조석관측 및 분석. 현장관측 지점과 동일 지점에서 1991년 8월의 1개월 관측자료 수집, 부산을 포함한 6개 지점의 장기 조석자료 수집 및 분석.
- 조류 : 1개 지점에서 단기 관측 및 분석. 동일지점의 1991년 8월의 단기자료 수집.

2. 분석 결과

- 대한해협 인근 해역의 조석현상은 계절변화 특성을 보이며 이 변화는 매우 체계적으로 나타난다.
- M2분조의 조차 및 위상 변화 특성은 frictional process로 설명할 수 있는 변화 특성을 보인다.
- 국부적인 월평균 해면 변화와 조석의 상호작용 효과를 나타내는 변화를 고찰할 때 계절별 해면변화가 조석의 계절변화와 관련된 것으로 보인다.

SUMMARY

I. Title

A Study on the Tidal Phenomena in the Seas Adjacent to the Korea Strait

II. Objective and Significance of the Study

The tidal phenomena for the adjacent seas to Korea has ever been investigated since early 1930's by Ogura. And in late 1970's a series of sdudy for this area is going on based upon numerical modelling method(An(1977), Choi(1980, 1988), Kang et al.(1988, 1991)) or analytical method(Kang(1984)). Also the newly edited tidal charts, using the analysis results of newly observed data recently, are suggested.

In relation to this topics Kang(1991) insisted that re-editing or correction be necessary, based on the results of numerical modelling and analytical study, and some integrated extensive measurements are required. This study was started to verify the hypothesis suggested by one of researchers of this study. Related to the purpose of study, first, an extensive analysis for tidal regime in the adjacent seas to Korea is to be required. And to get some background data to support the theory field measurement program is to be carried out at the several stations along the Korea Strait. The numerical experiment also seems to be necessary to verify the possible hypothesis for tidal vatiation in the study domain.

III. Contents and Results of the study

1. Field measurements

- Tide : 6 stations, Current : 1 station

2. Data gathering

- Tide : one month long data sets from the same 6 stations as field

measurement made during the August of 1991.
: several tens of year data at 7 stations including Pusan.
- Current : 1 station(short term data).

3. Results of study

- The difference of harmonic constants between two season does exist in the M2 constituent at the stations along Korea Strait. And the variation is very systematic.
- The characteristics of amplitude(and phase) variation can be explained by frictional processes.
- Considering the relation between MSL difference and interacting effect, the two variation seems to be closely related.

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Chapter 1 Introduction

Considering the tide propagation pattern in the Korea Strait it is evident that the incident tidal wave propagates from Yellow and East China seas, in which seas the tidal phenomenon is exclusively conditioned by those water-masses which penetrate through the canals between Ryukyu Islands, as noted by Defant(1961). The incoming tidal waves flowing into the East Sea are reflected along the coast of the Russia. So that, the tide characteristics in the Korea Strait is thought to be determined by the supersition of the incoming wave, reflected wave and independent tide generated in the East Sea. The possible role was simply investigated by 1 dim. mathematical modelling(Odamaki, 1989b) and 2 dim. mathematical modelling(Kang et al., 1991).

The above mentioned studies were mainly based upon the edited tidal charts(Ogura(1933) or Odamaki(1989a)) or mathematical modelling studies and critically on Ogura's study. Odamaki(1989a) concluded that some correction is necessary to the Ogura's tidal charts based upon the the charts edited using the recent tide data, but the number of tide data points along the Korean coast in the Strait is limited and also it is some questionable that the harmonic constants are stabilized.

In this circumstance Kang(1991) in the 6th Japan and East China seas study(JECSS) insisted that some variations of tide characteristics in the Korea Strait was expected based upon the mathematical modelling and theoretical considerations of frictional interactions between tide and mean current which is believed to have seasonal variations. Accordingly this study aims at investigating the time changes of tide characteristics by the direct observation of tide and currents as well as by the analysis of the existing long term tide data in the permanent stations located along the Korea Strait. Also in this study the tide data gathered in the Yellow and East China Sea have been also analysized to investigate the spatial variation characteristics of tides. The constituent considered in this study is mainly M2, as it is dominantly influenced through the interactions while other components are affected by at least two componets, which might obscure the existence of interacting phenomena.

Chapter 2 Measurements, data gathering and analysis

2.1 Measurements and data gathering

As mentioned in the introduction, field measurements for tide and currents were carried out during the summer and late winter seasons in order to investigate the possible time and spatial variations of tides in the Korea Strait, if those exist.

Water level readings along the south-eastern coast of Korea were two times taken at six sites simultaneously during the one month of, first, August 1991 and, second,of April 1992(see figure 1 and table 1). The instruments used for water level measurement consist of one Aanderaa type recorder(WLR-7) and five ones using the Paroscientific sensors of high accuracy. Data sampling interval was set to 5 or 10 minutes. In 1991 measurement period all the tide gauges were successfully recovered including Aanderaa WLR-7 installed at offshore station K6. The same recorder as installed in the first measurement was again used in the same site as chosen in the second measurement. The tide gauge at the offshore station(K6) was lost in the 2nd measurement campaign in 1992. The hourly variations of water level at observed stations are plotted in figure 2a for summer season data, and in figure 2b for winter season ones after the short time signals in the data were filtered out.

In addition to direct measurement long term hourly data have been collected at the permanent tide stations in the Korea Strait and along the Ryukyu islands through Korea Ocean Data Center(KODC), Korea Hydrographic Office(KORHO) and Japan Ocean Data Center(JODC). The location of those stations is represented as dark triangles in figure 3, where long term data of about 20 to 30 years were available to use in the permanent stations. Except for the period of mal-operation of the gauges the hourly data quality was generally good, as are checked by KORHO before issuing it and probably believed to be also checked by JODC.

2.2 Harmonic analysis of monthly and yearly data

Theoretically all the significant components of the tide could be separated from 18.6 years of observations. But experience has shown that one year is the optimum interval of observations to carry out a harmonics analysis : one year allows the separation of all the major components of the tide while their satellites are still not too far out of phase so that their interference can be taken into account with the help of nodal corrections : these are based on the assumption that the relative amplitude and phase of the components of the cluster present in the record conform closely to those in the tide generating potential, the latter easily calculated, as noted by Godin and Gutierrez(1985).

In this study 61 harmonic components have been included for one year long data analysis, while due to the component resolving problem 27 major components and 8 related components have been included for monthly data analysis, in which components are usually taken into account with the help of the known amplitude and phase relations from yearly harmonic analysis of the data in the neighboring permanent tide station. But, for monthly harmonic constants it is noted that there is a growing body of evidence that the amplitude and phase of constituents varies significantly from month to month, which has been demonstrated in the North Sea(Pugh et al.(1980)).

In following chapter we discuss the long-term (yearly or seasonal) variability of the major components. Considering the possibility of the existence of over(or under) corrections by nodal correction, as noted by Godin et al.(1986), We did analysize the monthly or yearly data, with and without nodal correction, to get harmonic constants reflecting such effects when necessary.

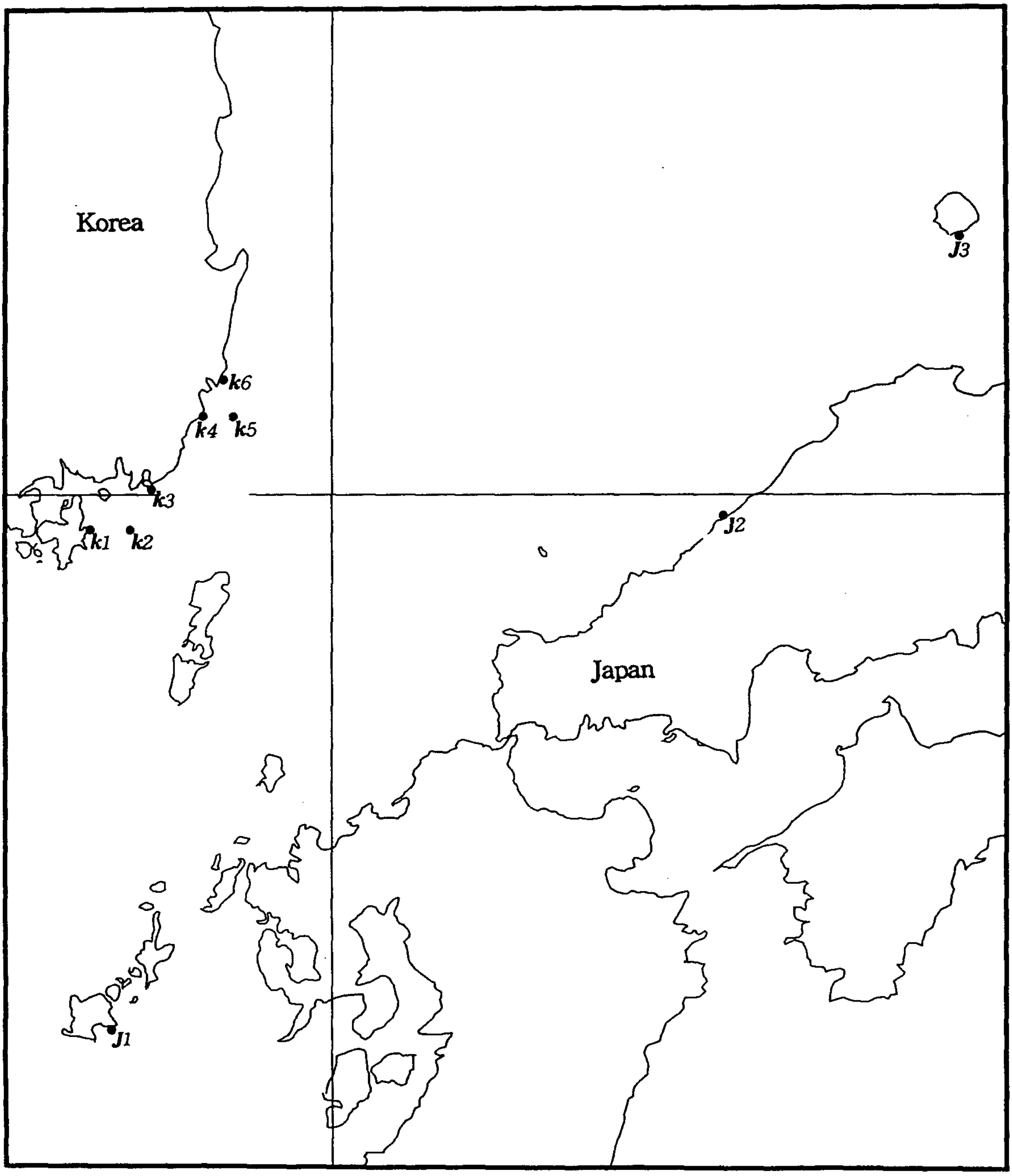


Figure 1 Measurement stations for tide(K1-K6) during August 1991 and April 1992 and data gathering stations for same period along the Korea strait.

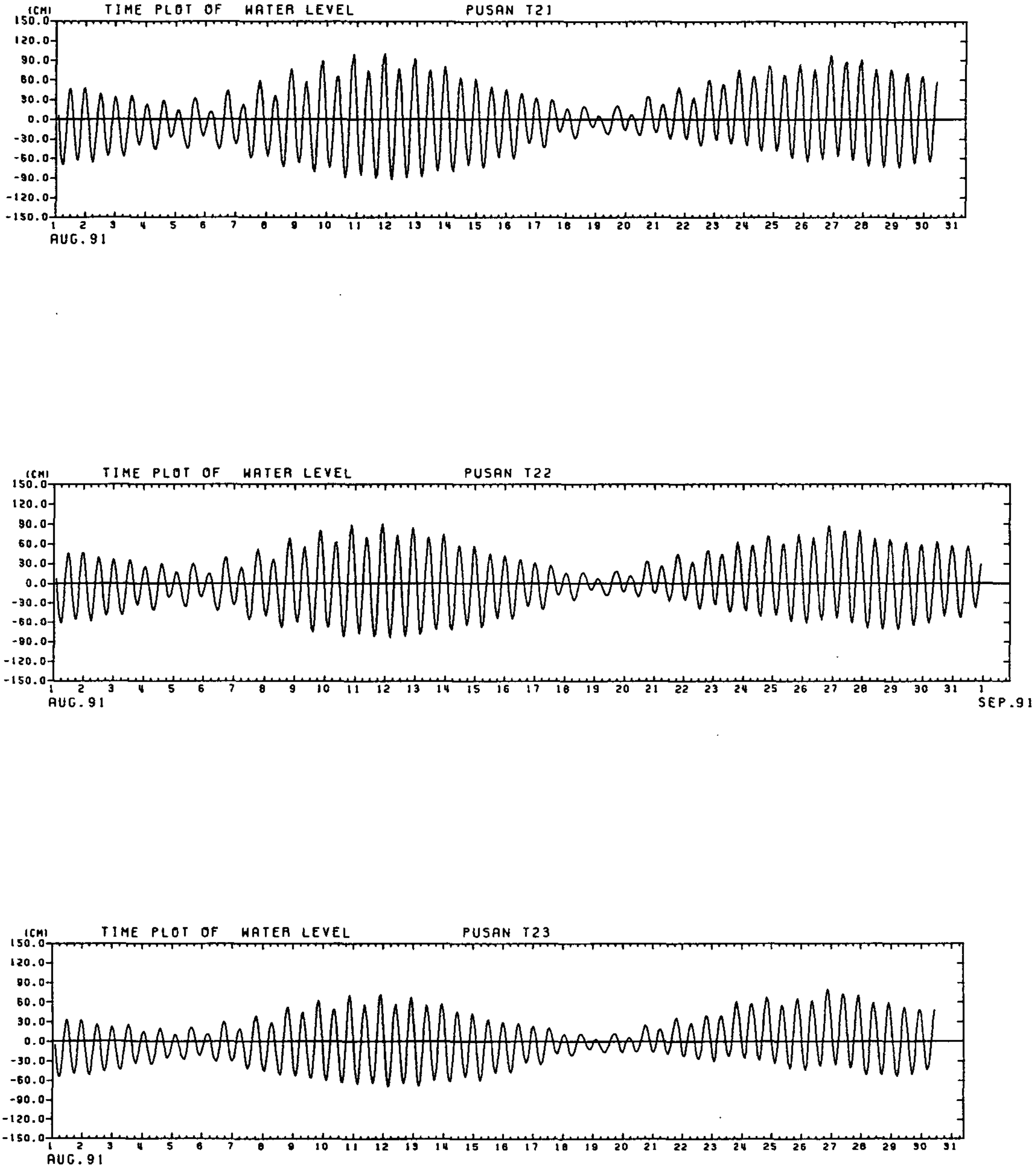
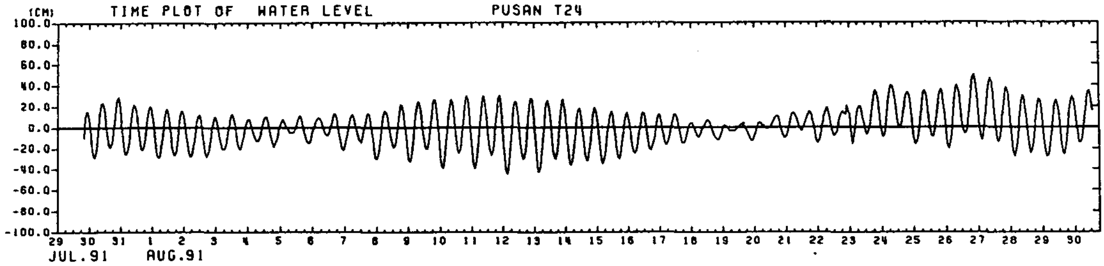
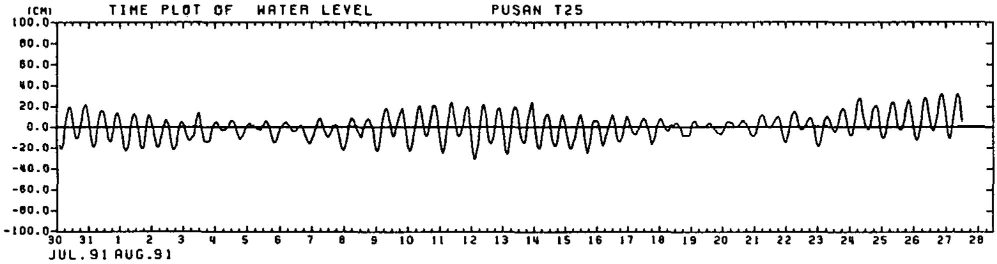


Figure 2a Water level variation at K1,K2,K3,K4,K5 and K6 in August 1991.





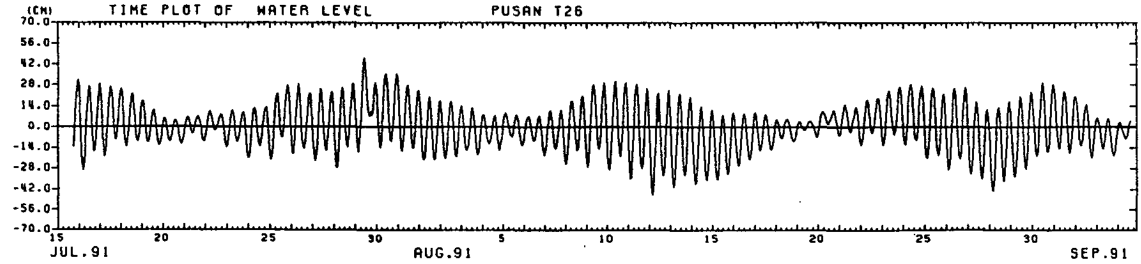


Figure 2a (Cont'd).

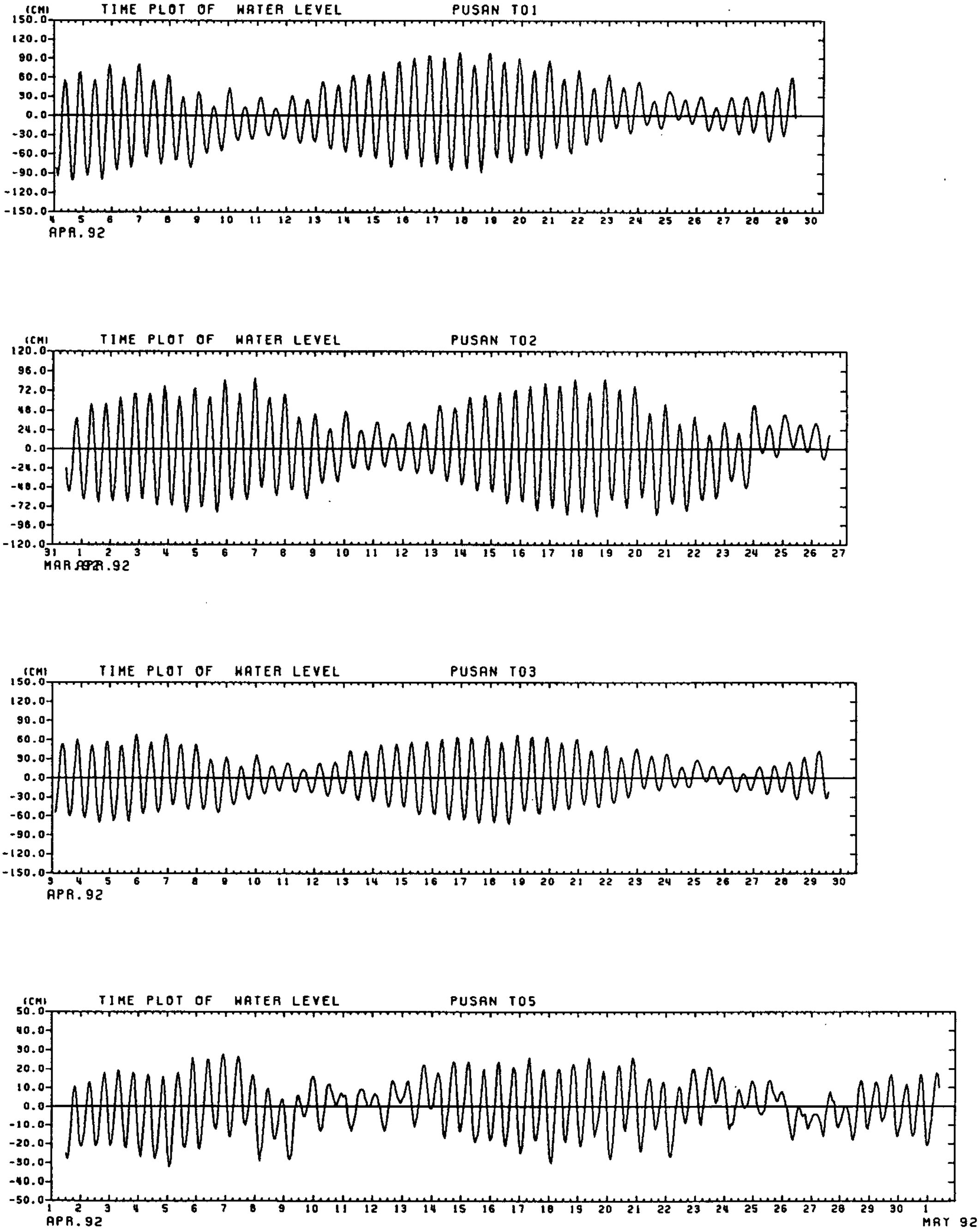


Figure 2b Water level variation at K1,K2,K3,K4,K5 in April 1992.

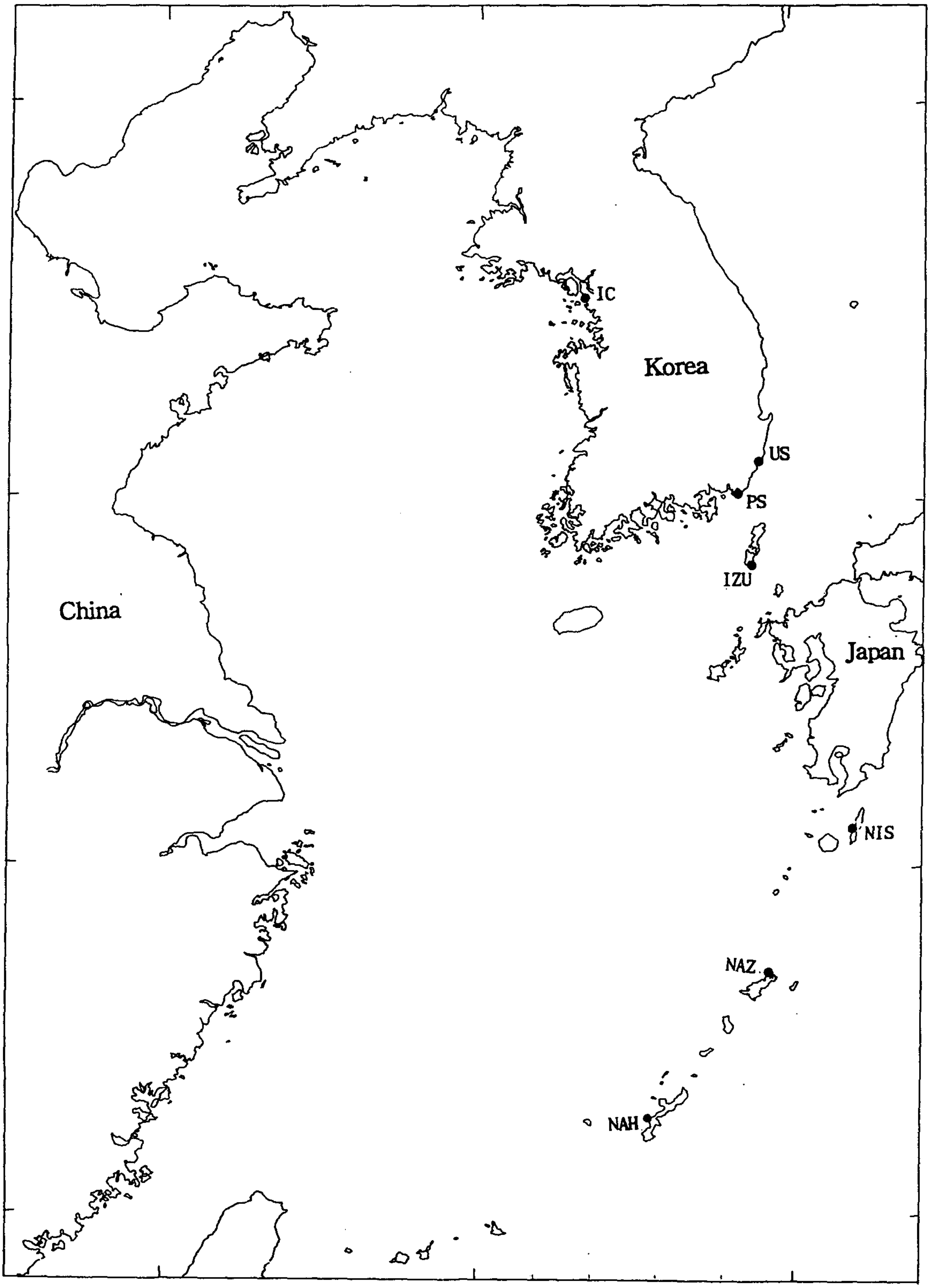


Figure 3 Station map of data gathering in the existint permanent tidal station along Ryukyu Islands and Korea Strait and Yellow Sea.

Chapter 3 Monthly and yearly variations of tides

3.1 M2 tide in the Korea Strait on August 1991 and April 1992

As described in chapter 2, a simultaneous measurement of tide levels was mounted by KORDI over a month at selected stations marked as K along Korean coast and the data from 3 permanent tidal stations marked as J along Japanese coast were also obtained to get a comprehensible picture of tidal wave throughout Korea Strait. The harmonic constants of M2 component with nodal corrections are given at table 2 and 3, in which the data used for analysis are from contemporary measurements, so that we can expect the consistent results.

First, the trend of amplitude decrease toward the East Sea(Japan Sea) is quite manifest. This kind of decreasing pattern is very well known from recently edited tidal charts by Nishida(1980), Odamaki(1989) and mathematical model result(Kang(1991)). Second, for the phase lag(g) the cyclonic rotation in M2 tide propagation is also shown, comparing it with cotidal line of tidal charts or model result, which is an indication of the reliability of the measurement and analysis systems.

One important aspect of the results is that the amplitudes of M2 component in August 1991 are larger that those of M2 component in April 1992. The amplitude differences seem to be too large to neglect it as it might be caused by statistical errors. Meanwhile, the absolute value of phase lag in April 1992 are larger than those in August 1991, indicating later high waters in April 1991 at each station. And the variations of amplitudes and phase lags seem to be quite systematic, even though we admit that there is a growing body of evidence that the amplitude and phase of constituents varies significantly from month to month. Accordingly we should comment that the amphidromic system might experience corresponding changes for individual months as phase lag in each station varies each month.

We are in a position to consider whether this kind of variation is physically meanful or not, because the potential theory of tides does not explain why this kind of variation occurs. Here there exist three possibilities for these systematic changes of amplitude and phase in various stations. One possibility is that these changes are originated from outside region of Korea Strait. The other is that this change is internally caused, that is, by interaction between tide and other physical phenomena with in the strait. The last possibility is that this systematic change is caused by the superposition of dynamical interaction between tide and other event inside the strait and interaction outside the strait. To investigate some details for this phenomena long term tide data along Korea Strait have been collected through JODC, KODC and KORHO, which have been used to yield monthly variation characteristics. Before scrutinity of the monthly harmonic values we decided to check the yearly variation of tides for finding possible yearly variation in this area.

Table 1 Details of field maesurements(K1-K6) and data gathering stations along the Japanese coast(J1-J3) in August 1991 and April 1992.

Station(name)	Location(Lat.,Long.)	Period	Data quality
K1(Yanjiam)	34° 52'24"N, 128° 44'53"E	1991.8, 1992.4	good , good
K2(Namhyongje)	34° 52'52"N, 128° 57'32"E	" , "	" , "
K3(Saengdo)	35° 01'56"N, 129° 05'40"E	" , "	" , "
K4(Janggikap)	35° 21'54"N, 129° 21'31"E	" , "	" , bad
K5(off Ulsan)	35° 20'06"N, 129° 29'56"E	" , "	" , lost
K6(Bangojin)	35° 28'29"N, 129° 25'51"E	" , "	" , ?
J1(Fukue)	32° 42' N, 128° 51' E	" , "	" , good
J2(Hamada)	35° 54' N, 132° 04' E	" , "	" , "
J3(Saigo)	36° 12' N, 133° 20' E	" , "	" , "
C(off Ulsan)	35° 20'22"N, 129° 28'24"E	" , "	" , "

Table 2 M2 amplitude(H) along the Korea Strait from the harmonic analysis of contemporary monthly data

Korea coast		Japanese coast	
st.	H(cm)(Aug.1991,Apr.1992)	st.	H(cm)(Aug.1991,Apr.1992)
K6	(12.65 ,14.76)	J3	(5.79 , 6.24)
K5	(16.48 ,lost)		
K4	(18.50 ,bad)	J2	(7.83 , 8.51)
K3	(37.37 ,40.80)		
K2	(46.37 ,48.96)		
K1	(50.94 ,54.16)	J1	(76.98 ,79.00)

Table 3 M2 phase lag(degree) along the Korea Strait from the harmonic analysis of contemporary monthly data

Korea coast		Japanese coast	
st.	g(deg)(Aug.1991,Apr.1992)	st.	g(deg)(Aug.1991,Apr.1992)
K6	(214.55 ,211.44)	J3	(57.53 , 59.03)
K5	(222.80 ,lost)		
K4	(217.61 ,bad)	J2	(347.47 ,350.05)
K3	(235.62 ,240.32)		
K2	(243.20 ,244.27)		
K1	(242.61 ,243.81)	J1	(231.61 ,234.42)

3.2 Yearly variations of tides

Based upon the findings in the contemporary measurements along the Korea Strait the necessity was raised to study the long term variations of tides in the region through which tidal wave propagates into Korea Strait, which was also thought to be necessary to investigate in which scale this kind of variation occurs. So that, long term tide data along the Ryukyu islands, where the tides generated in the Pacific Ocean arrive, have been analysized as well as long term tide data in the Korea Strait, as shown in figure 3.

The basic reason for choosing the stations as shown in figure 3 is related to the tide propagation characteristics in adjacent seas to Korea peninsula. In fact, the tidal waves passing through the Ryukyu islands experience its deformation first by abrupt depth change from 2000m to 200m and, next, the branch propagating into Yellow Sea is again influnced by lateral land boundaries. This branch of wave propagates as Kelvin waves into the Yellow Sea and analytical study of tidal waves for the bay was studied by Kang(1984). The other branch of wave flowing into Korea Strait is superposed with the reflected waves in the Russian coast of the East Sea where the effect of independent tide is to be considered.

In this report the analysis results at three stations among the stations, Naze(NAZ), Ulsan(US) and Inchon(IC) are presented. As mentioned earlier, 61 components have been included in one year long data analysis. The yearly variation characteristics of 5 constituents among them are presented in following figures. At station NAZ for the year of 1965 to 1991 the yearly variations of amplitudes of components, M2, S2, O1, K1 and N2 are plotted in figure 4a, while the yearly phase variationa are plotted in figure 4b, which station is located at the Ryukyu islands. The amplitude and phase variations at station US in the Korea Strait are shown in figures 5a and 5b. And the results in the inner station IC of Kyunggi Bay of the Yellow Sea are plotted in figures 6a and 6b.

As described earlier, the analyses have been done with nodal correction and without nodal correction, as the nodal correction is thought to cause over correction or under-corrections for each component, as noted by Godin et al.(1986). At Naze(NAZ) the 18.6 year variation of diurnal components(O1, K1) are clear for the analysis without nodal correction and in case of nodal correction the amplitude and phase lag are stabilized to nearly constants. The deviations of amplitude and phase for K1 is about 2.4cm(12.1%), 9.2 degree , while the deviation for O1 is about 2.8cm(18.7%), 11.2 degree. For M2 component 18.6 year variation of amplitude is also clear for the case without nodal correction , but for phase lag the variation is not so clear compared with amplitude variation. The amplitude variation range of M2 component is about 2.6cm(4.5%). The amplitude and phase of S2 component, which are theoretically not influenced by nodal correction, seem to vary more or less randomly. In case of N2 component 9 and 18.6 year variations are seen to be superposed.

At Ulsan(US) the yearly variations of diurnal-component(O1, K1) also show the dominant 18.6 year variation, but more deviation seem to exist compared with that at Naze. The absolute values of amplitudes are largely decreased and the amplitude and phase deviation from nodally corrected constants are about 0.5cm(14.8%), 8.6 degree, respectively, for O1, while those for K1 are 0.6cm(21.5%), 11.8 degree, respectively. For M2 component 18.6 year variation of amplitude is also clearly shown, but not for phase lag. Generally the amplitude and phase variations at Ulsan are more irregular than those at Naze.

At Inchon(IC) the variation of amplitude and phase lag are presented in figures 6a and 6b. This site is well known for its large tidal range, as easily checked by the amplitudes of major components. The amplitude and phase lag of diurnal components(O1, K1) show regular sinusoidal curves for the case without nodal correction, but in case with nodal correction the constants are stabilized to nearly constants as those at Naze. The amplitude and phase deviation for O1 component is 5.0cm(12.8%), 8.1 degree, and 6.0cm(21.0%), 12.1 degree for K1 component, respectively. And the 18.6 year variation for M2 component in case without nodal correction is more clear than at Ulsan and Naze. But, even though the component of M2 is nodally corrected the variation range of amplitude is about 10cm, which is not a negligible value. Also one thing to note here is that the amplitude and phase of S2 show some variation which seems to be driven by frictional effect between M2 and S2, as noted by Godin et al.(1986).

The characteristics of yearly variations in these three representative stations can be summarized as follows:

- The 18.6 year variations are clear for the amplitude and phase of diurnal-components in case without nodal correction analysis, with relatively more irregular pattern at Ulsan than at Naze and Inchon. The harmonic constants in case with nodal correction are stabilized to nearly constants, but at Ulsan more irregularity occurs.
- For M2 component at station Naze, from which M2 tidal wave propagates toward the coastal area, regular 18.6 year variation is found in case without nodal corrections and the values are stabilized to nearly constants for the case with nodal correction. But more irregular variations of harmonic constants appear at Inchon and Ulsan. And except for Naze's case nodal correction does not seem to contribute much to stabilize the harmonic

constants.

- The frictional effect for S2 component by M2 component seem to exist at Inchon where large tidal range occurs to cause the interaction between components.

The irregularity of signal appearing in specific case of Saint John inside the Bay of Fundy have been discussed by Godin(1992), which irregularities present, he described, are authentic and do not reflect a failure of the analysis process. The irregularities appearing in our data are also thought to be authentic because the amplitude of M2 at Naze, for example, are stabilized to a nearly constant without irregularity. Also this study is based upon the basic idea that some irregularity or deviation from constant values, in the case with nodal correction, should exist by interaction between tide and other dynamical parameters, for example, meteorological effect or others.

The characteristics of the yearly harmonic constants do not show any clear evidence of variations under the present circumstances. Meanwhile, the monthly values of amplitude and phase, in August 1991 and April 1992, showed some systematic variation, which might be interpreted as the shorter period process being present than the yearly variation. So that, the monthly variations at several stations have been investigated in next section.

3.3 Monthly and seasonal variations of tides

As noted in section 3.2, the monthly variations of harmonic constants at several stations in the study area have been investigated for 9 years(1965-1973), which is about half nodal period. And if some effects by nodal correction problem or so exist, such effect will occur within 9 year period.

As mentioned earlier, ther exist monthly variations of harmonic components, one of the reasons for such monthly variations may be due to the effects which are introduced by other components, of neighboring frequency, not included in analysis. To estimate such effects and delete such influnces in our study a technique has been introduced. We have the harmonic components of 61 components after harmonic analysis of one year long period of 1 hour interval data every year. Then, we predict one year period of data with 1 hour interval using the 61 harmonic constants and divide it into 12 one month data sets. Eventually we have two kind of data sets for certain month. One is an observed data set of one month long and the other is a predicted one. We did analysize two sets of data each month to obtain 27 major components and 8 related components. From now we call harmonic constants from observed hourly data 'observed(OBS) harmonic constants' and those from predicted hourly data 'estimated(EST) harmonic constants'. And also we analysize monthly data to get harmonic constants without nodal correction as we thought that the analysis with nodal correction might cause over or under correction described in earlier section. But, in fact, if we do use same method for two set of data each month, the results are thought to be consistent in otherwise case.

M2 component is first expected to be affected if the interaction between tide and other effects exists as its amplitude is usually the largest of the resolved harmonics components. In case of other components smaller in its magnitude of amplitudes the interaction between that component and other physical process will be more complicated than that between M2 and physical process. So that, our study is refined to only M2 component case.

At Naze the monthly variation for 9 years of M2 harmonic components are plotted in figure 7a-7d. In figure 7a, the line linked by circles(o) represents the observed amplitude from the observed water level and the other line linked by cross(x) denotes the estimated amplitude from the predicted water level. Both the observed and estimated amplitudes show clear monthly variations. But, in contrast to the estimated amplitudes, the observed values show seasonal variations. The estimated values seem to have more high frequency oscillations. To investigate the variation characteristics of the observed values thoroughly the pure variation effects have been computed by subtracting the estimated values from the observed amplitudes, which effects we call here interacting effects. Figure 7b shows the monthly evolutions of interacting effects in which the seasonal variation for amplitude is clearly shown. In summer season the interacting effect terms have positive peaks while in winter season the effects have negative peaks. The mean amplitude of M2 at Naze is about 55cm, then positive or negative range of interacting effect is about 3-4%, which is of nearly same order of magnitude compared with the variation range by nodal modulation. Also the variation appears quite systematically. For phase lag similiar results are obtained, but the seasonal variation is out of phase with the amplitude variation as shown figure 7c and 7d. In other words, at summer season the observed amplitude is larger than the estimated amplitude while the observed phase is smaller than the estimated value.

At Naha(NAH in figure 3) located at the central position of Ryukyu islands the hourly data for whole year are available from 1967. The monthly variation of amplitudes for the observed and estimated hourly data is plotted in figure 8a and the monthly interacting effects in figure 8b. The similar trend seems to exist at Naha, but seasonal variation is not so clear as at Naze. These two sites are distinguished from each other in that Naha is located at the parallel station to the path of the Kuroshio ocean current, but Naze at the cross direction to it.

The monthly variations of amplitude, phase and interacting effect terms at the stations along the Korea Strait(Pusan and Izuhara) are shown in figure 9 and figure 10. The seasonal variations of the observed amplitude and phase at both stations are shown more clearly than at Naha or Naze. The interacting effect also show dominant seasonal variation pattern. The relations between phase and amplitude at each station are again out of phase. But the monthly amplitude variation between Pusan and Izuhara is in phase and also in phase for phase lag. The amplitude ranges to mean values are about 5.3%, 2.7% for Pusan and Izuhara, respectively.

At Inchon biannual variation seems to be dominant in both the observed and estimated values as shown in figure 11. But monthly interacting effect again shows a seasonal variation. Excluding some peak values in 1972 the variation range of amplitude is about 1.8%, if considering that vatiation, about 3.0-3.3%. In contrast to amplitude interacting effect the phase interacting effect is not so clear.

The monthly variations of interacting terms obtained by subtracting the estimated harmonic constants from observed ones clearly show the trend for seasonal variation characteristics at 5 stations. One of the results to note is that the amplitude and phase lag at each station is out of phase. Also the spatial variation of interacting terms has some time lag between area. The interacting effect of amplitude for 5 stations are collected and shown in figure 12 and in figure 13 for phase lag. Except for Naha seasonal variations of amplitude interacting appear apparently. Spatially the interacting terms are in phase between Pusan and Izuhara. Also the interacting terms between Naze and Inchon are nearly in phase. Meanwhile, several month lag between Pusan(or Izuhara) and Naze(or Inchon) exists. This kind of characteristics are quite interesting because such a systematic variation seems to be related to other physical processes.

It is expected that the seasonal variation might be related to the monthly mean sea level difference at the sites of interest. In chapter 4 some preminary investigation for the relation between mean sea level difference and tides is done.

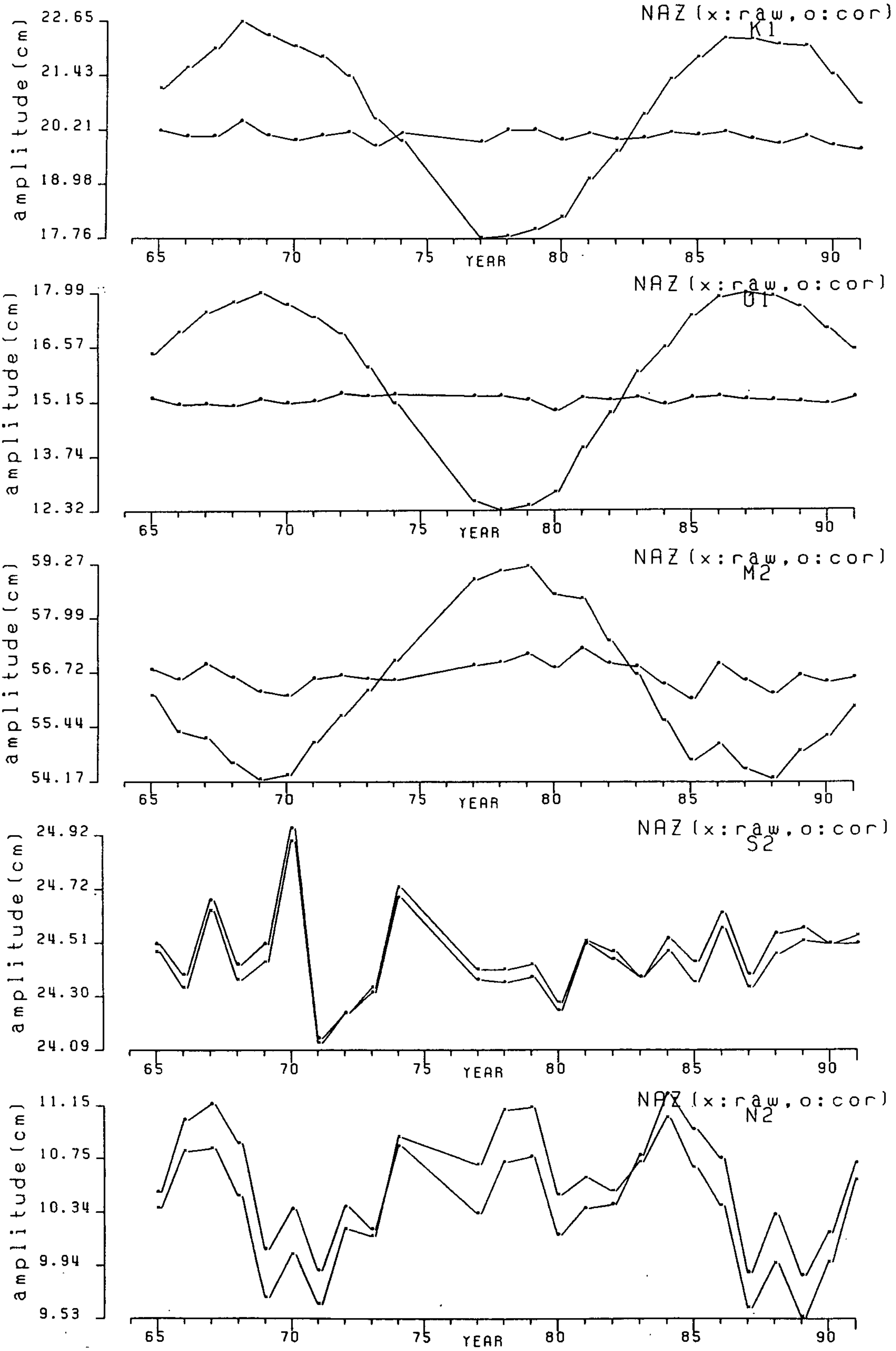


Figure 4a The yearly variation of amplitudes of O1,K1,M2,S2 and N2 for the year of 1964 to 1991 at Naze.

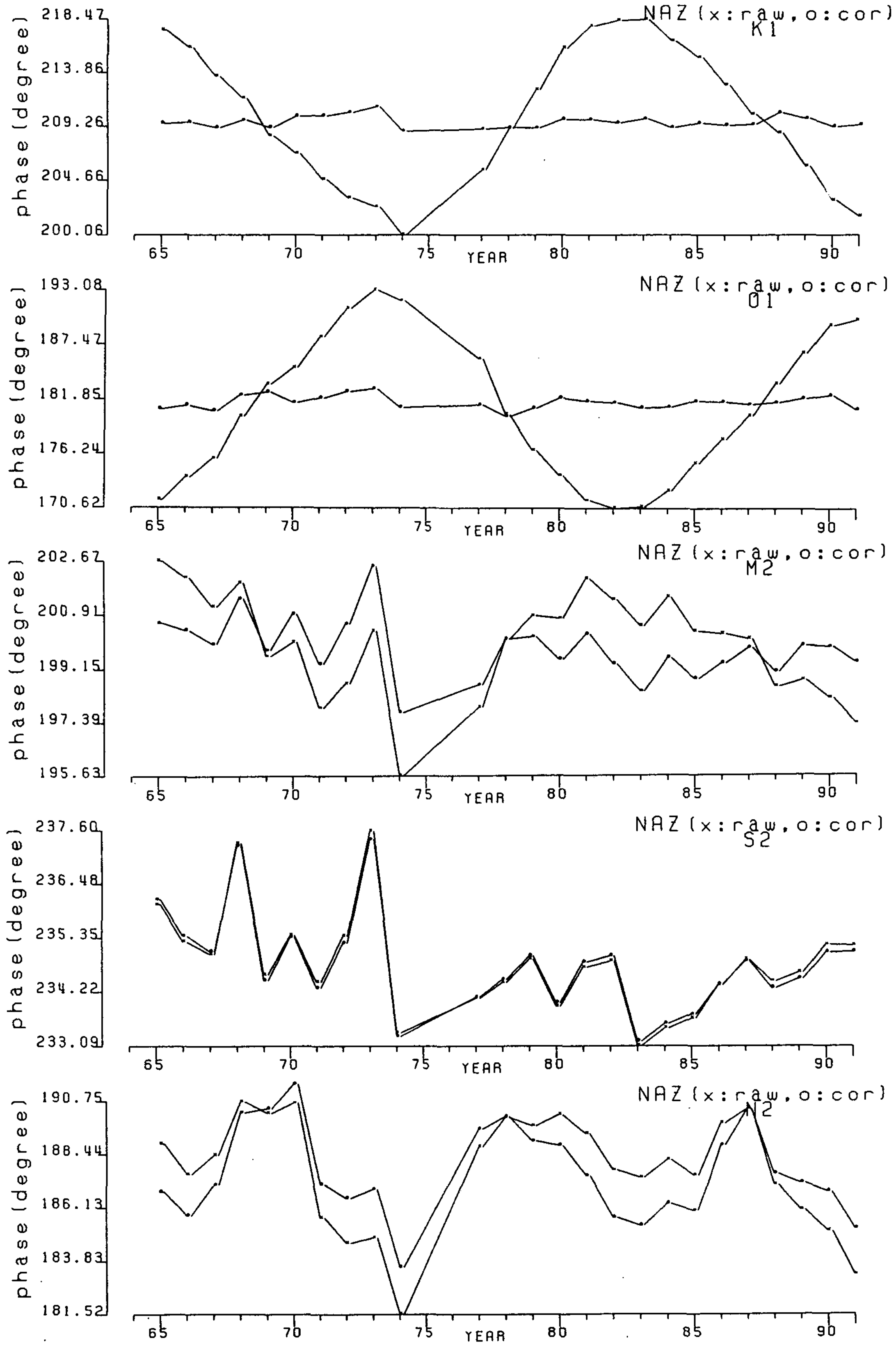


Figure 4b The yearly variation of phase lags of O1,K1,M2,S2 and N2 for the year of 1964 to 1991 at Naze.

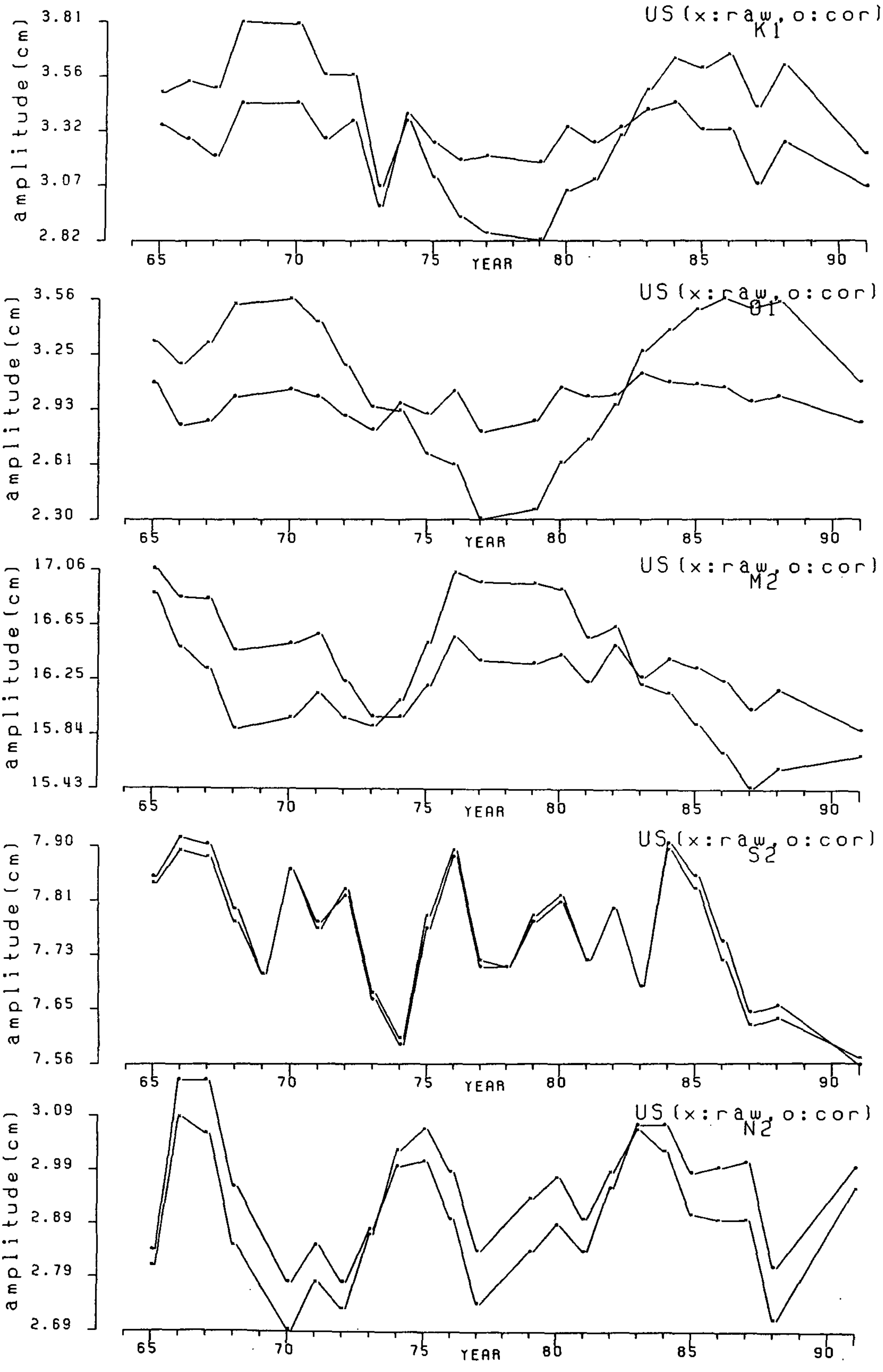


Figure 5a The yearly variation of amplitudes of O1,K1,M2,S2 and N2 for the year of 1964 to 1991 at Ulsan.

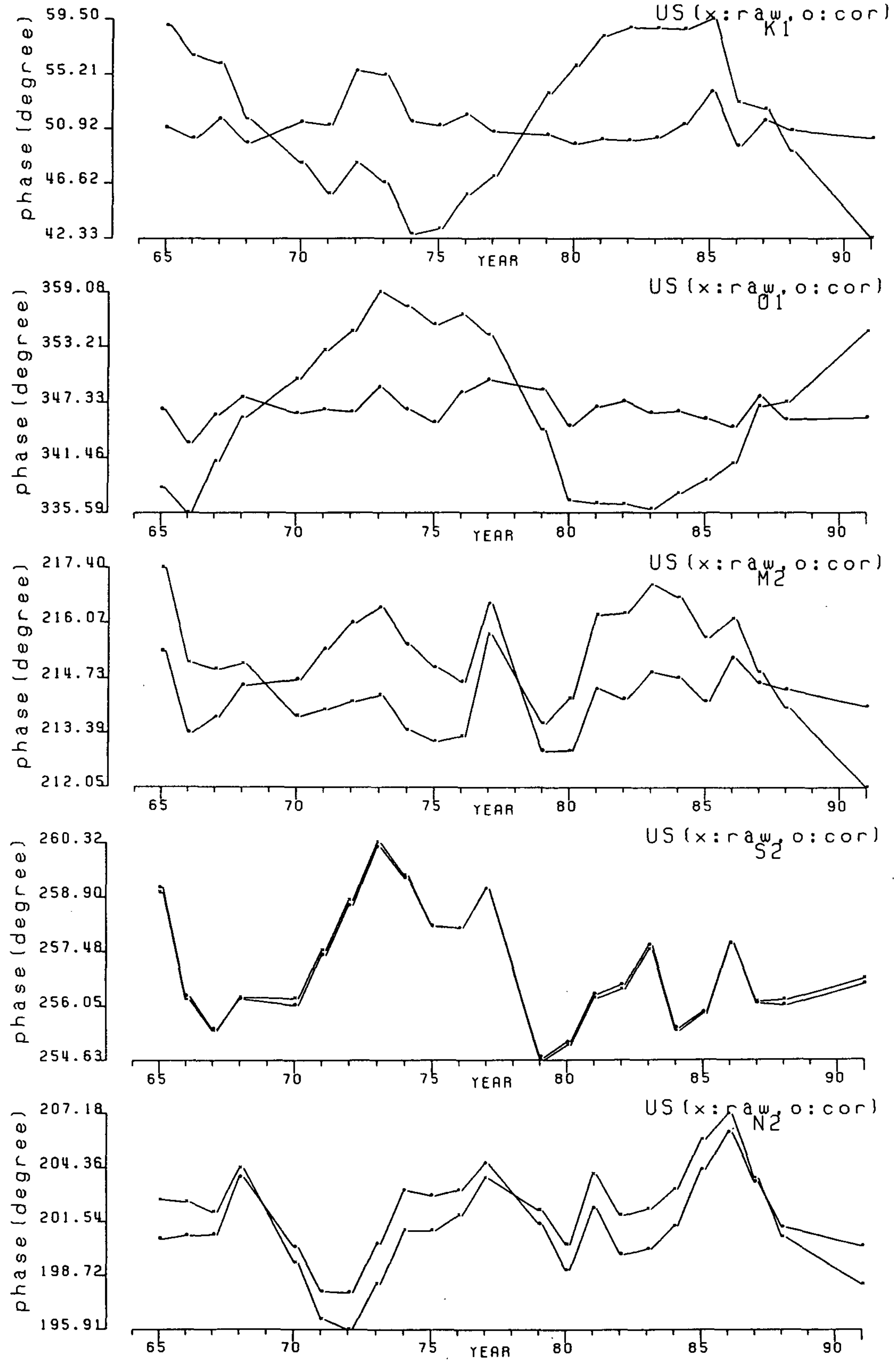


Figure 5b The yearly variation of phase lags of O1,K1,M2,S2 and N2 for the year of 1964 to 1991 at Ulsan.

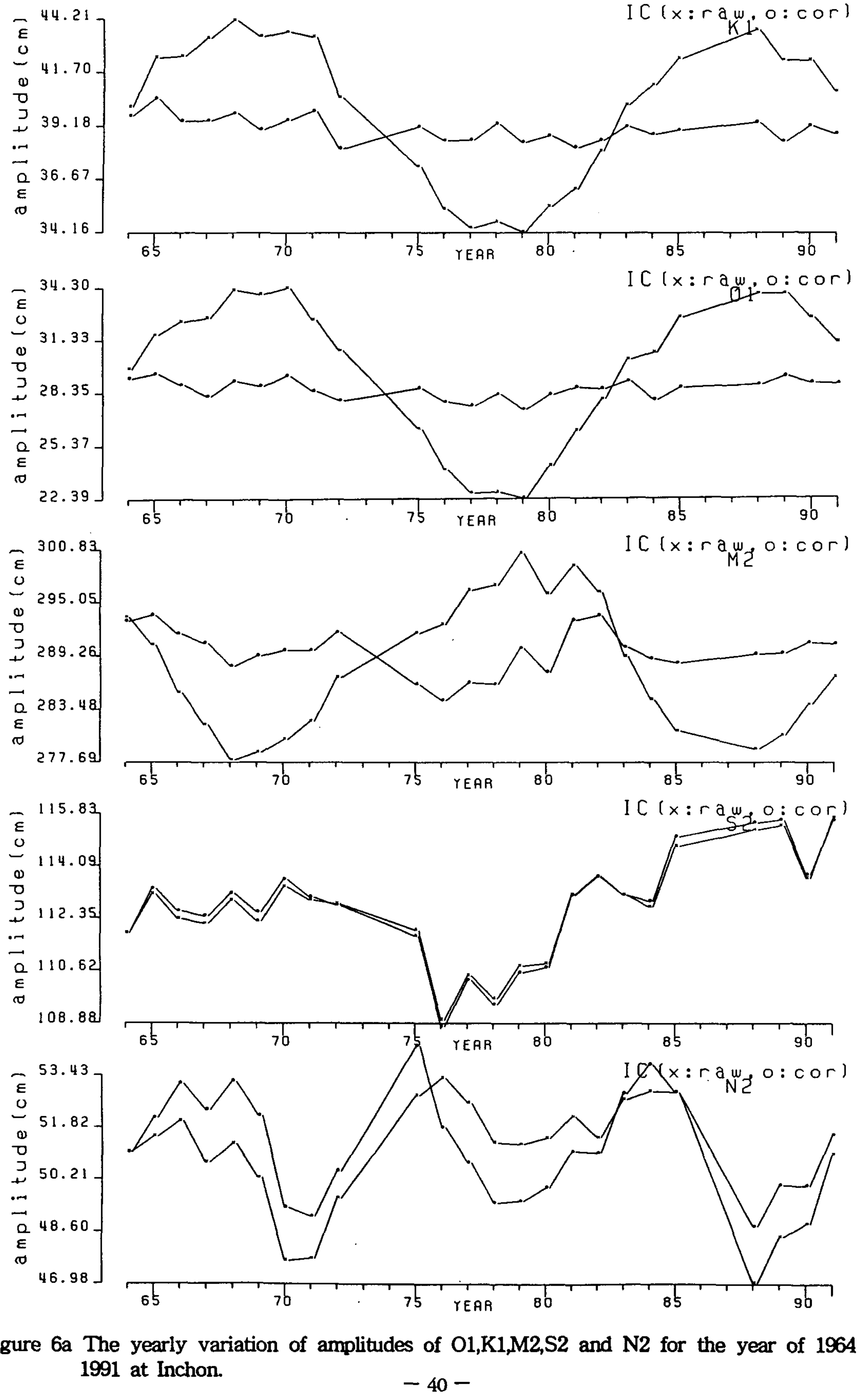


Figure 6a The yearly variation of amplitudes of O1,K1,M2,S2 and N2 for the year of 1964 to 1991 at Inchon.

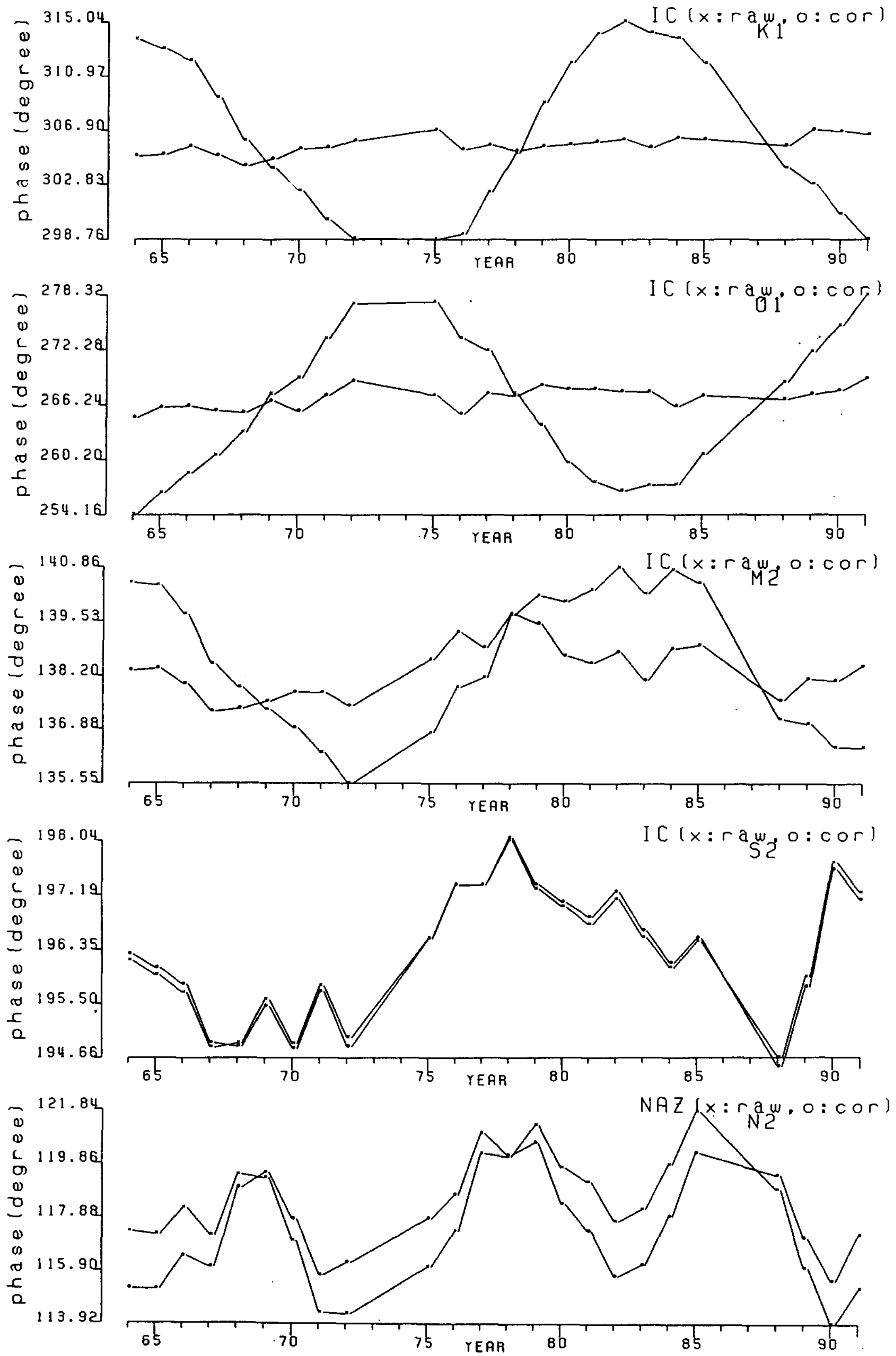


Figure 6b The yearly variation of phase lags of O1,K1,M2,S2 and N2 for the year of 1964 to 1991 at Inchon.

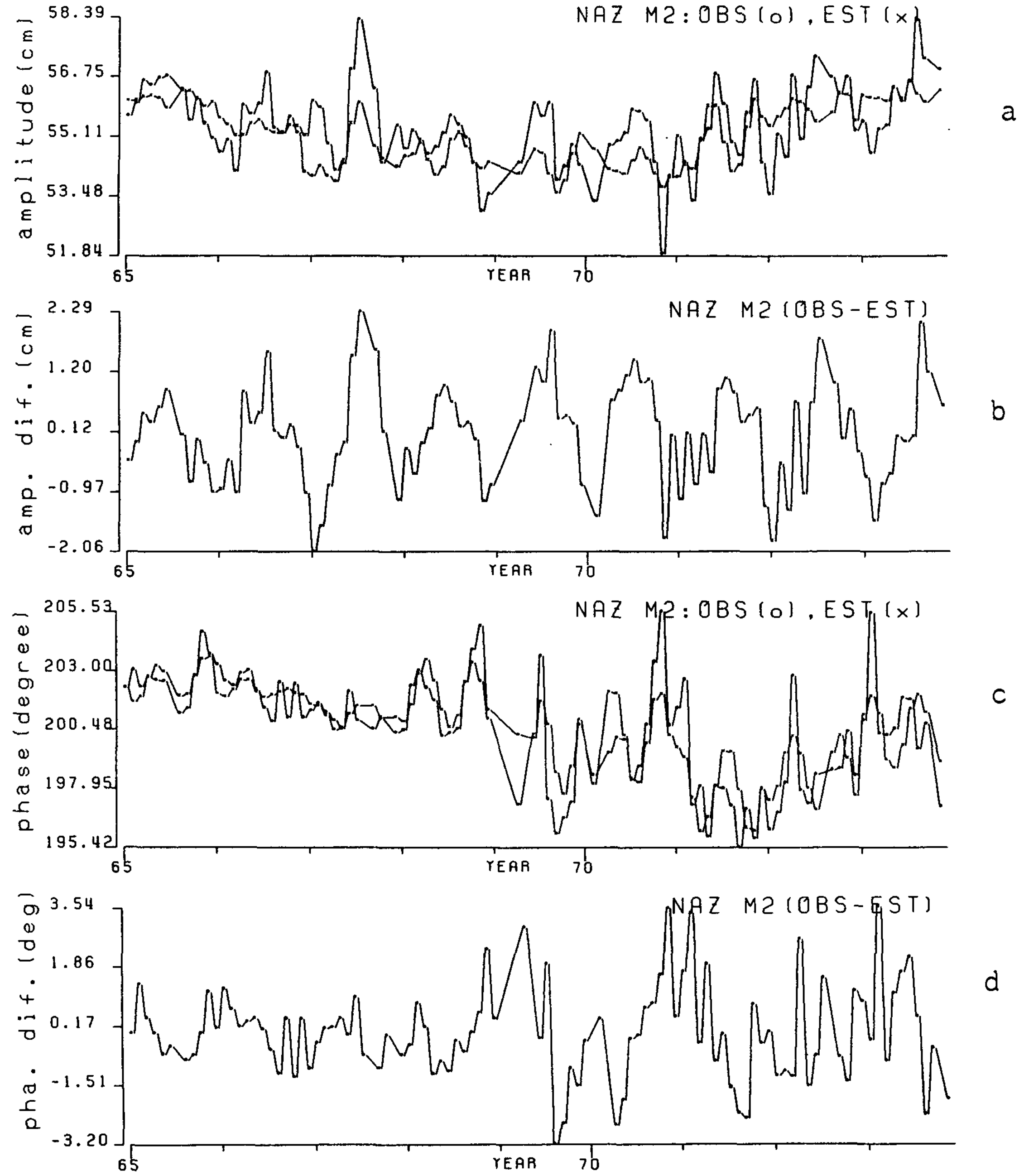


Figure 7 Monthly variation of M2 hamonic constants and interacting effect terms in Naze during the period of 1965 to 1973(a:amplitude, b:amplitude interacting term, c:phase, d:phase interacting term).

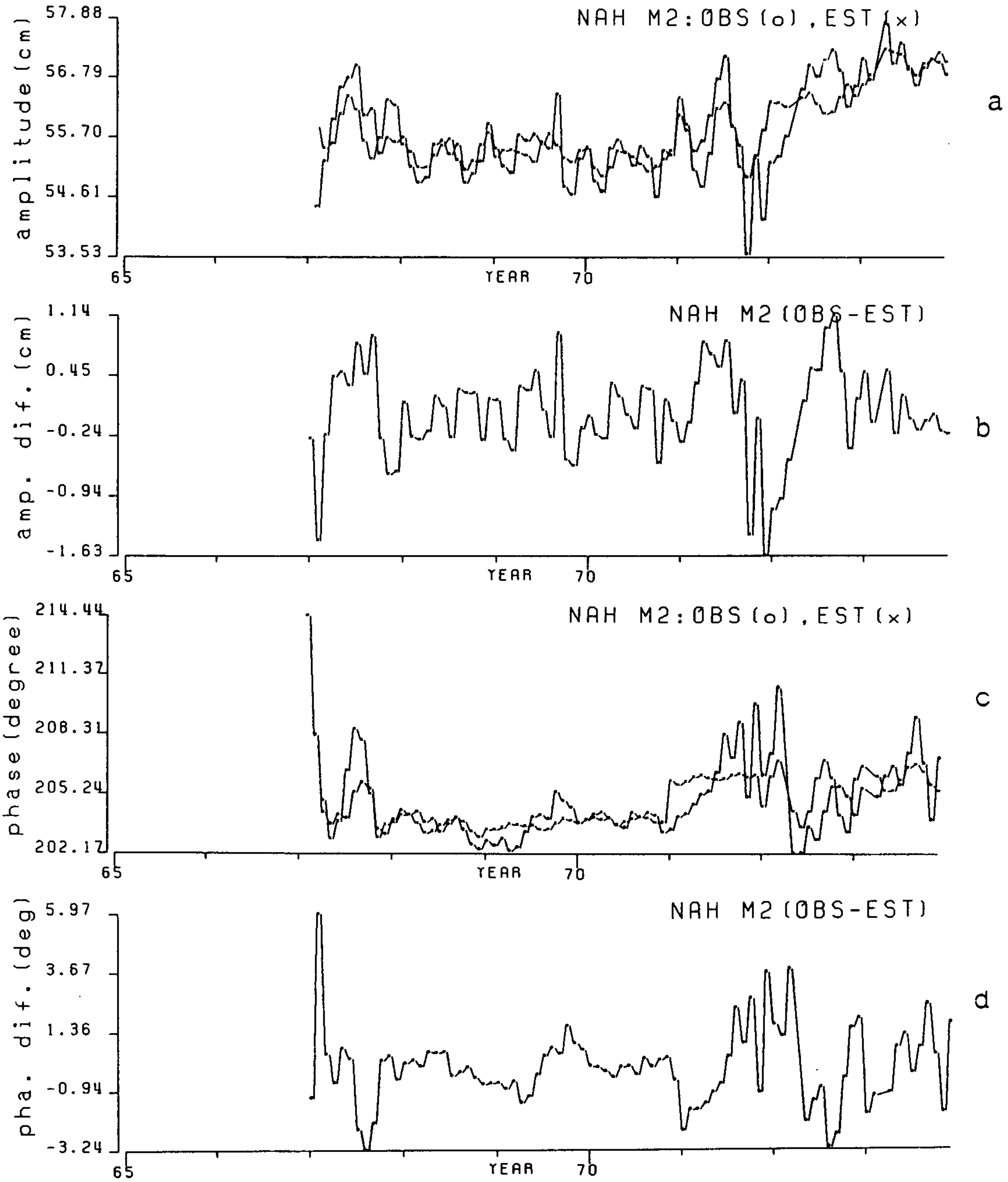


Figure 8 Monthly variation of M2 hamonic constants and interacting effect terms in Naha during the period of 1965 to 1973(a:amplitude, b:amplitude interacting term, c:phase, d:phase interacting term).

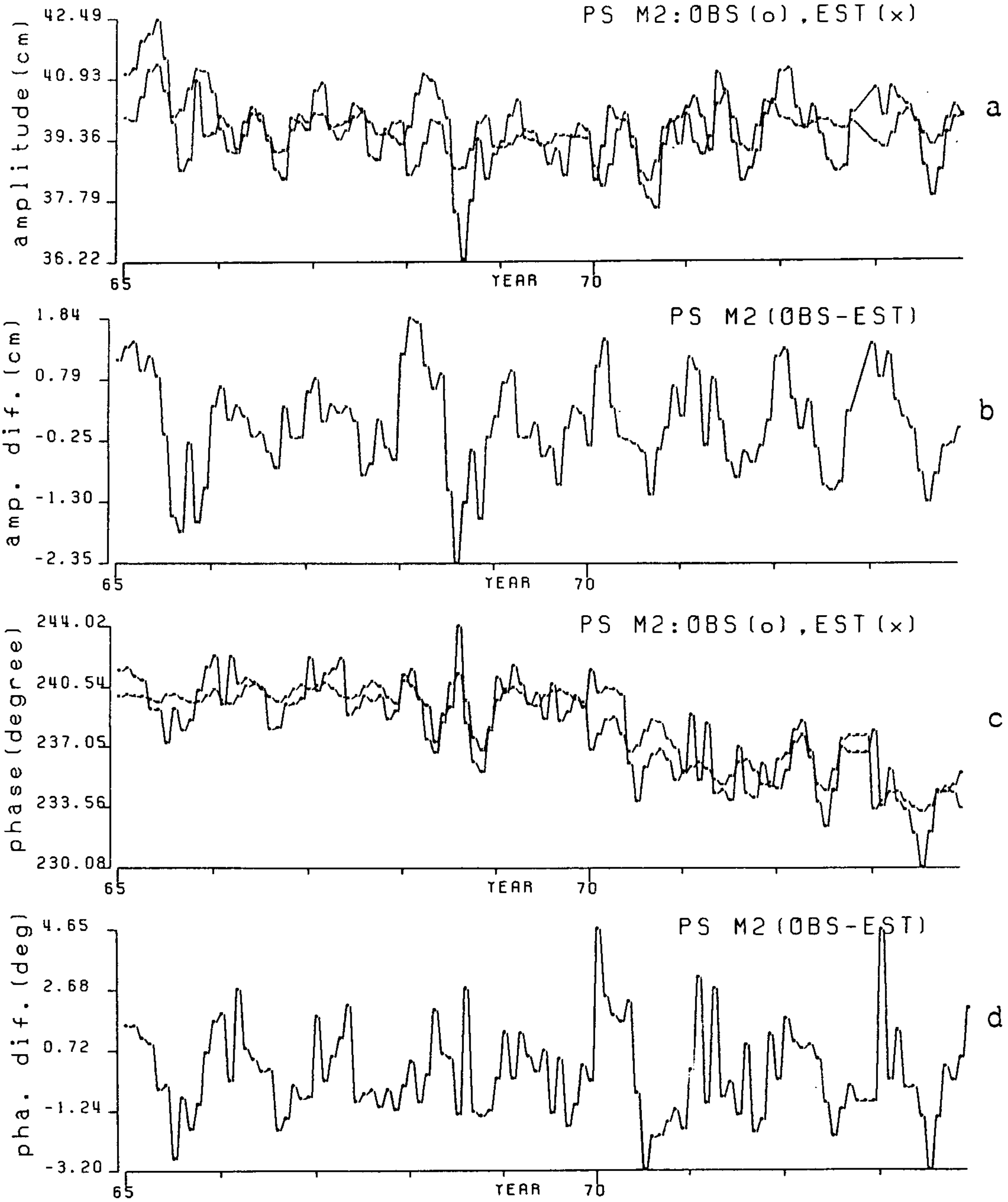


Figure 9 Monthly variation of M2 hamonic constants and interacting effect terms in Pusan during the period of 1965 to 1973(a:amplitude, b:amplitude interacting term, c:phase, d:phase interacting term).

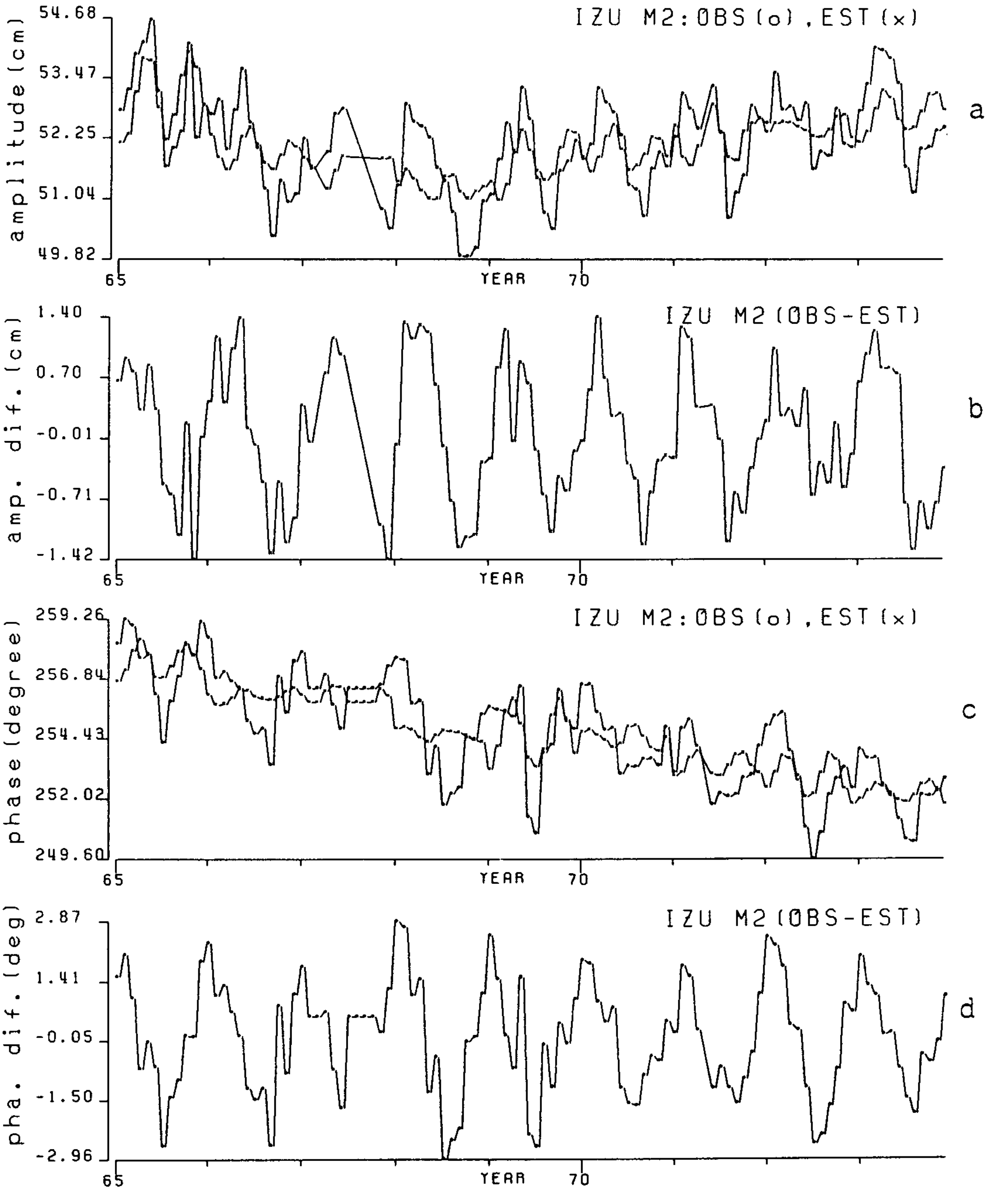


Figure 10 Monthly variation of M2 hamonic constants and interacting effect terms in Izuhara during the period of 1965 to 1973(a:amplitude, b:amplitude interacting term, c:phase, d:phase interacting term).

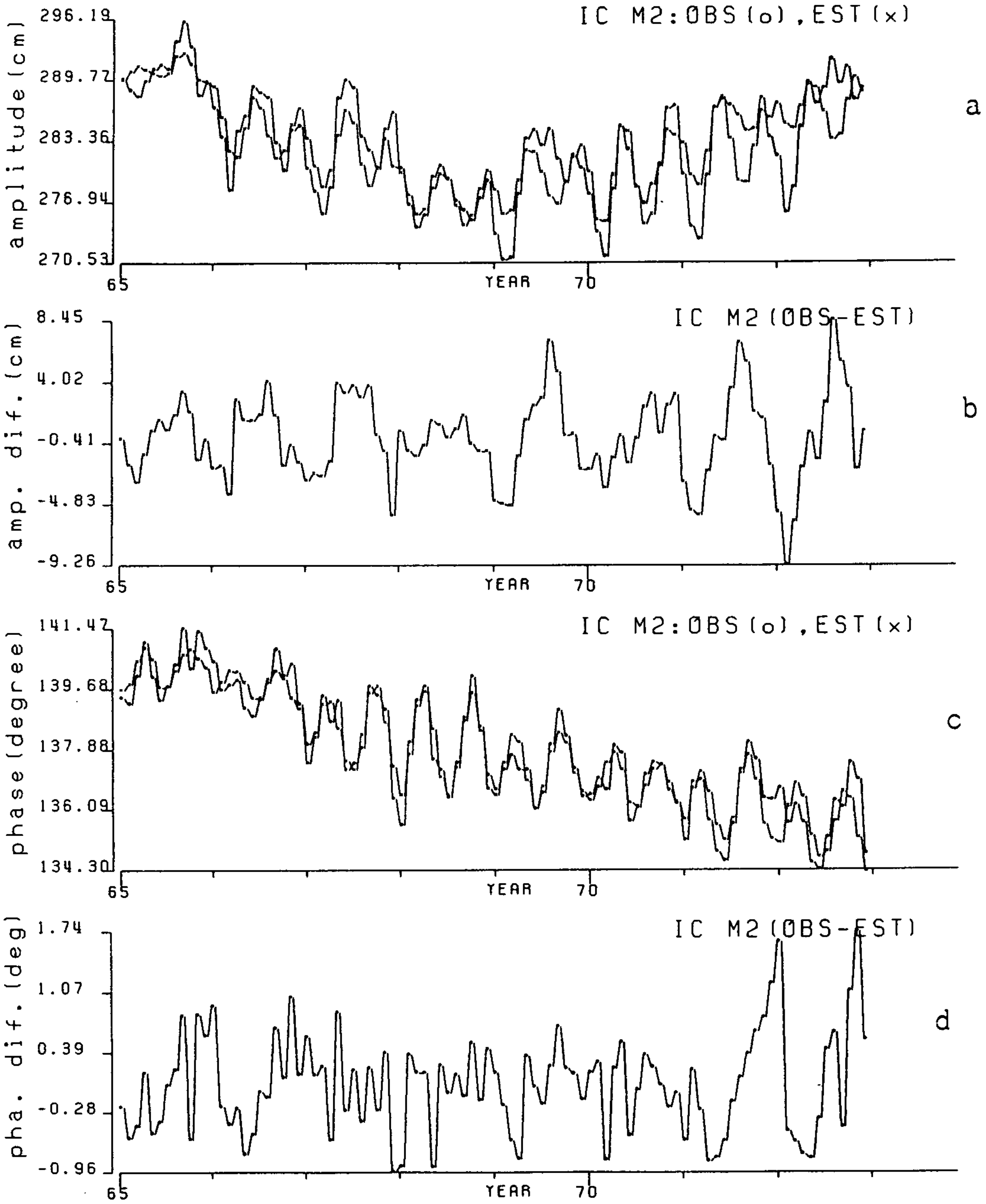


Figure 11 Monthly variation of M2 hamonic constants and interacting effect terms in Inchon during the period of 1965 to 1973(a:amplitude, b:amplitude interacting term, c:phase, d:phase interacting term).

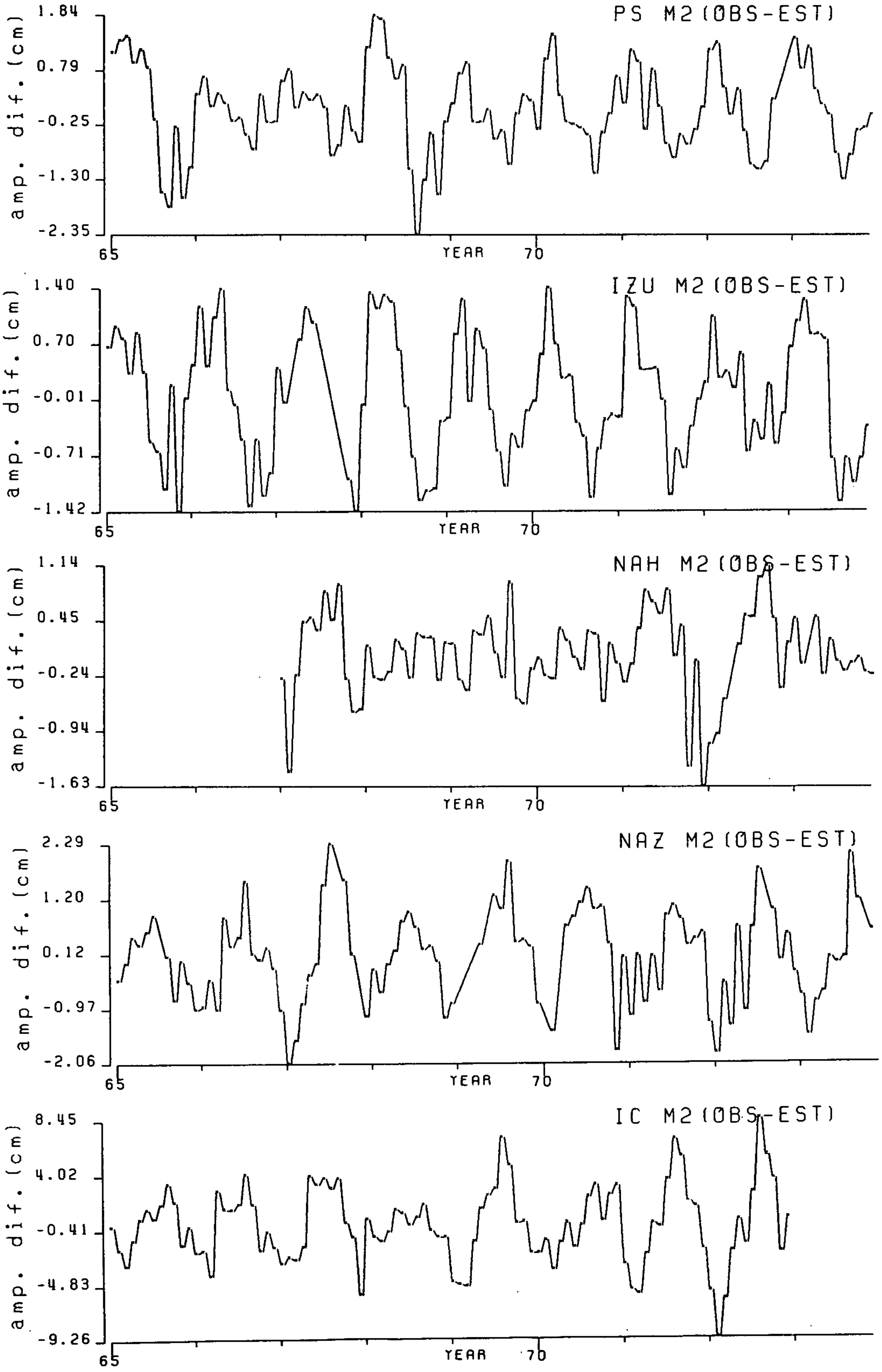


Figure 12 Monthly variation of M2 the amplitude interacting effect terms at Pusan, Izuhara, Naha, Naze and Inchon for the year of 1965 to 1973.

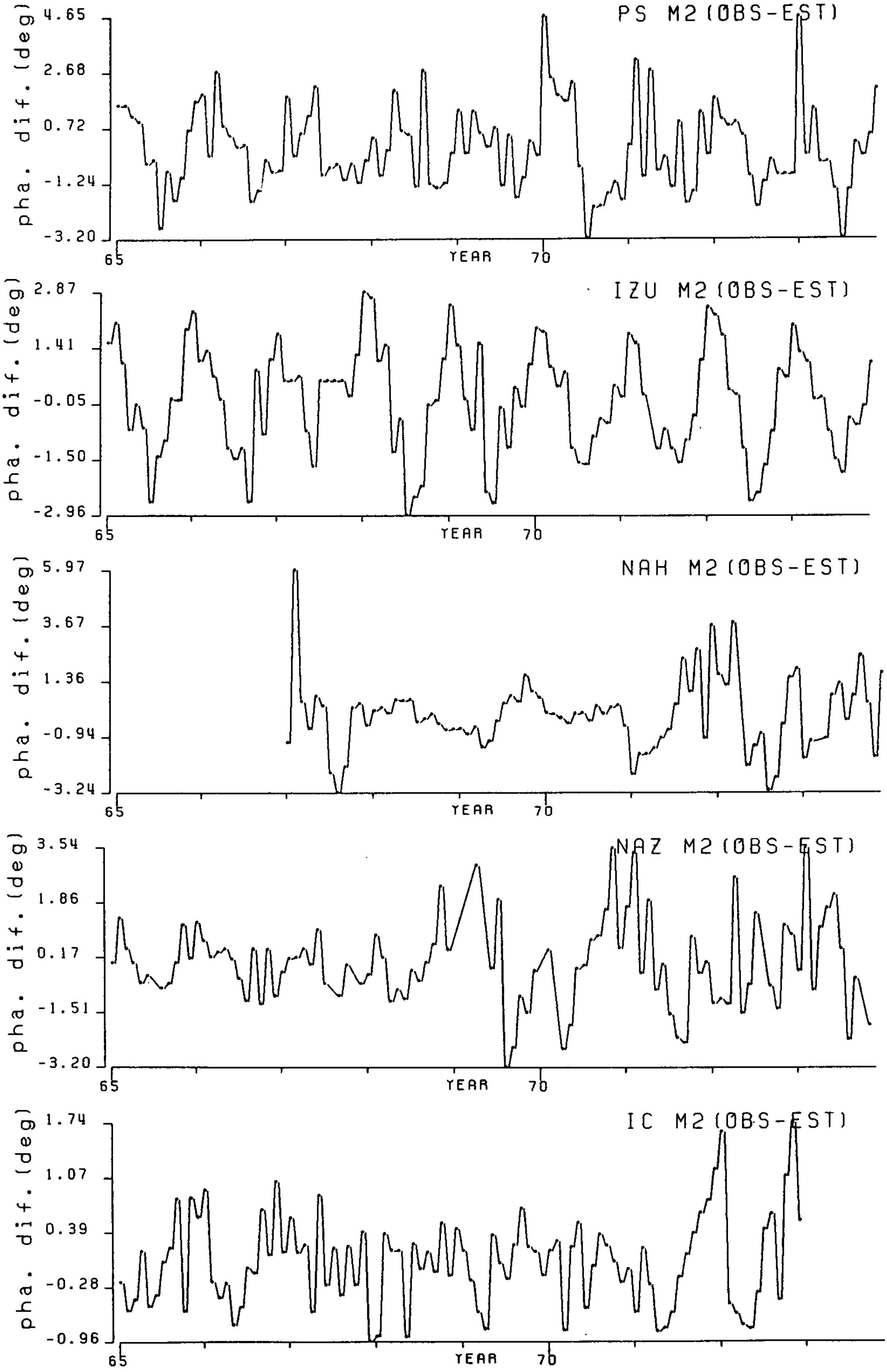


Figure 13 Monthly variation of M2 the amplitude interacting effect terms at Pusan, Izuhara, Naha, Naze and Inchon for the year of 1965 to 1973.

Chapter 4 Relation between tides and MSL difference

4.1 General

Many authors(Yih(1969) and others) investigated the relation between mean sea level difference and ocean currents along the Korea Strait to get some coefficients for fitting linear relation between sea level difference and measured currents. The linear relation can be found between currents and sea level difference under the assumption that the dynamics in the considered system can be approximated by geostophic relation.

The local monthly mean sea level data at 4 stations(Izuhara, Pusan, Naze and Nishinoomote) have been gathered to evaluate the monthly sea level difference at western channel of the Korea Strait and at the Tokara Strait as shown in figure 3. One month period has 57.968 times M2(44714s) periods and almost all the tidal effects are expected to be cancelled out by simple monthly mean. Also meteorological effects to local MSL have been assumed to be negligible because the meteorological effects are also cancelled out as the length scale of atmospheric event is generally larger than the distances between Pusan-Izuhara or between Naze-Nishinoomote.

4.2 Relation between interacting term and MSL differences

The monthly variations of local mean sea level differences across Pusan-Izuhara have been obtained by subtracting the monthly mean sea levels at Pusan from the monthly mean sea levels at Izuhara as Tsusima current flows into the East Sea. At the Tokara Strait through which the Kuroshio current flows again into the nothern Pacific Ocean the monthly mean sea level differences have been obtained by subtracting the monthly mean sea level values at Nishinoomote from those at Naze.

The monthly variations of mean sea level(MSL) difference at straits are shown in figure 14. The seasonal variation of mean sea level differences at the Korea strait occurs while biannual characteristics in the Tokara Strait appear. One thing to note is that the amplitude interacting effect terms are in a reverse phase with MSL difference at stations located in the Korea Strait. For the Tokara Strait it is difficult to define some definite relations, but implicitly it can be said that there still exist some relation between seasonal variations of the interacting term and MSL difference.

At this time of study it is difficult to say that some dynamical relation between MSL difference and the interacting terms, but some relation between two effects might exist from the dynamical consideration. Further studies related to this topics are required to find the dynamical relations.

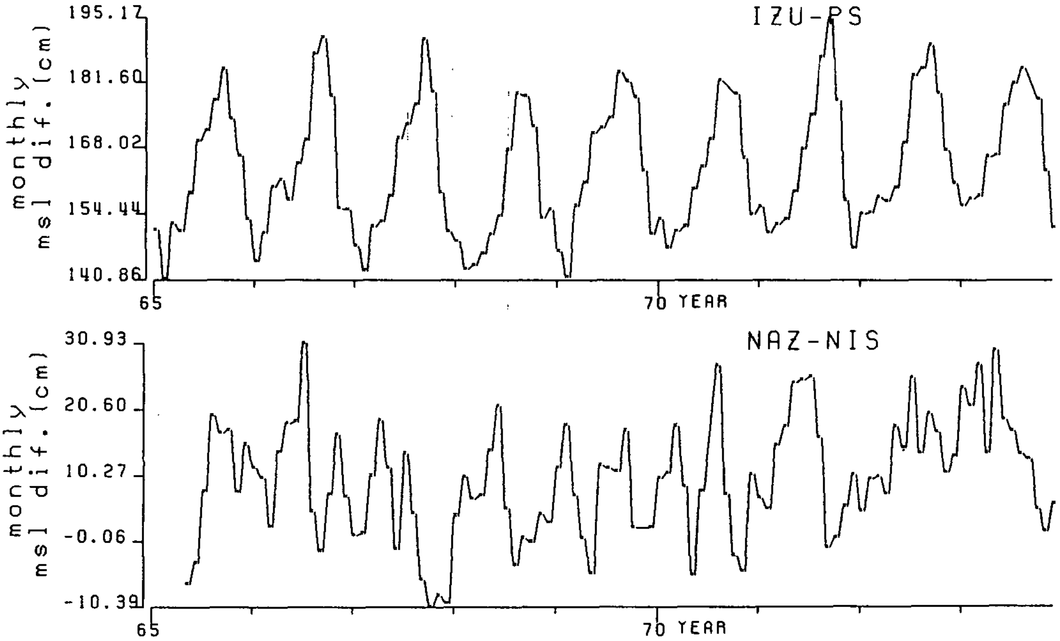


Figure 14 The monthly MSL differences at Izuhara-Pusan and Naze-Nishinoomote.

Chapter 5 Conclusion and discussion

The monthly and yearly variation characteristics of tides have been investigated, through the monthly analysis of hourly tide data, at the several stations along the Korea Strait and the Ryukyu islands. The observed harmonic constants have been analysized to have a seasonal variation pattern and the effects defined as 'interacting effect' were also shown to have a firm trend of seasonal variation, which is not explained by equilibrium theory of tides. The seasonal variation pattern of M2 harmonic constants is expected to be realistic due to its systematic variation in the study areas.

Accordingly an attempt to explain the possible dynamics for the interacting effects was to relate it to monthly variation of ocean currents such as the Kuroshio current and the Tsusima current. The order of magnitude of Tsusima current in April 1992 can be estimated based upon the observed results, as shown in figure 15. Ocean current characteristics in the seas adjacent to Korea peninsula have not been much known. The Kuroshio ocean current flowing along the continental slopes off Ryukyu islands is known to follow a weak meandering path. A branch of the Kuroshio current or some part of the Kuroshio flows into the East(Japan) Sea through the Korea Strait. The relation between MSL difference and the interacting effect terms has been simply discussed as MSL differences reflect the current variations at sites considered in this study.

The interactions between tides and other physical phenomena are first expected to occur through the frictional effects as the nonlinear process by the advection effect is limited considering the order of magnitudes of tidal current and mean current. Further investigation is to be carried out, related to the theoretical point of view. The two-dimensional model experiment with a localized inclusion of mean flow has been done to estimate the possible role of the interactions. As expected, the results have shown that generally overall decrease of amplitudes in study area appears with reasonable order of decrease, which results seem to be promising to investigate the background dynamics. Some detailed results for this experiment will be included in the next study.

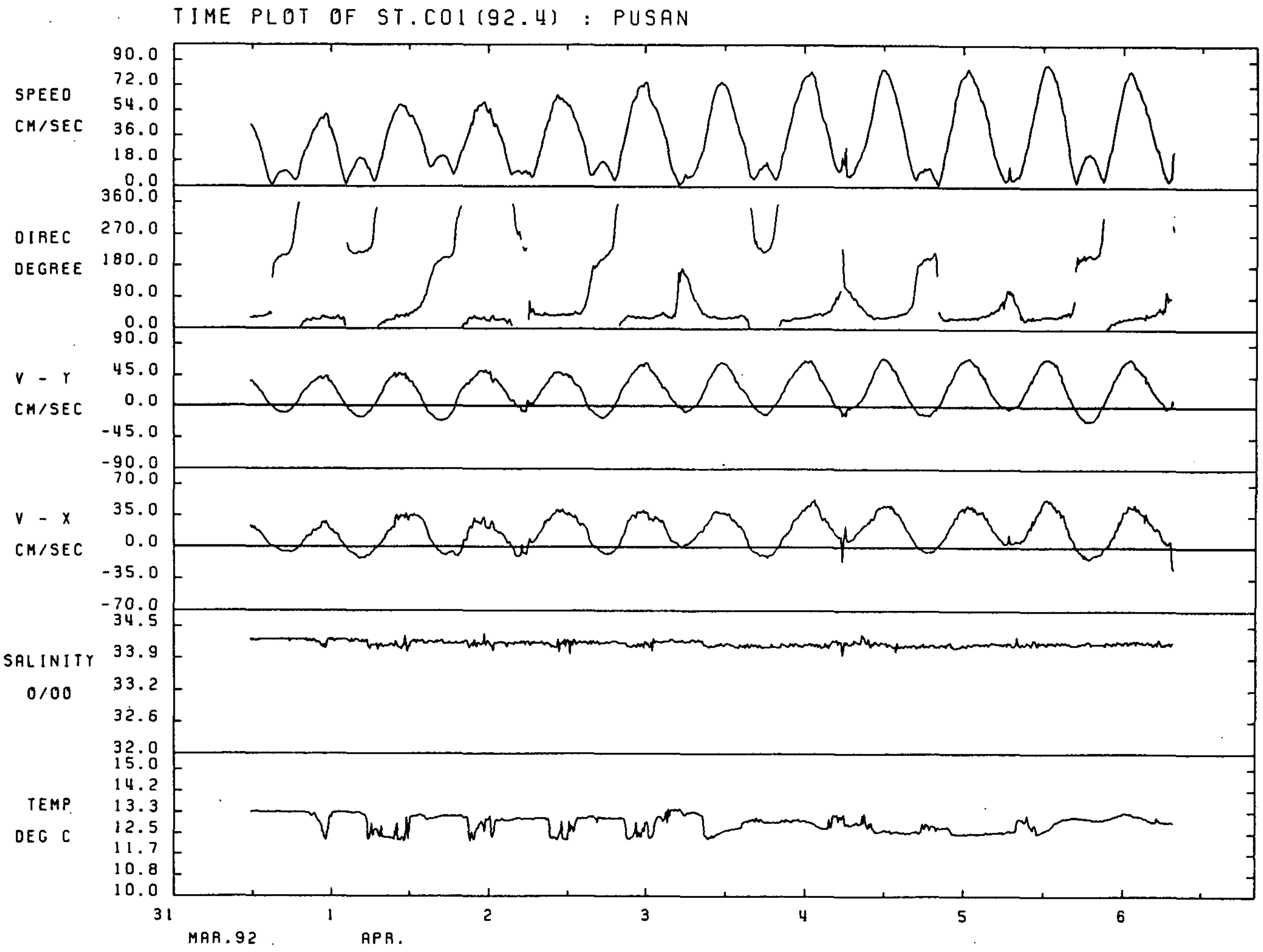


Figure 15 Results of current observation 10 mile off Ulsan.

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