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The worldwide distribution of the seasonal cycle of mean sea level

by

P. L. Woodworth

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BIDSTON

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ABSTRACT

Measurements have been made of the average seasonal cycle of mean sea level at 390 tide gauge stations distributed across the world. For the four oceanic coastlines in the Northern Hemisphere, the wealth of data permits the major contributors to the cycle to be identified and discussed. On a worldwide scale, the general features of the MSL seasonal cycle are displayed, reduced to its annual and semiannual components. Contrary to the conclusions of previous work, there is no clear evidence for the astronomical contribution to the seasonal cycle observable in sea level records.

1. Introduction

Some thirty years have elapsed since the classic review of the worldwide seasonal cycle of mean sea level (MSL) by Pattullo et al (1955). In spite of much additional research being done on the subject in the intervening years (notably by Lisitzin and coworkers), and there being good recent compilations of seasonal data in certain regions of the world (for example, Wyrtki and Leslie's study of Pacific MSL (1980)), a further worldwide review at this time is not unreasonable, primarily because there is a larger quantity of data available now than there was thirty years ago, and also because there is frequently a need in sea level research for the average variation of MSL to be clearly understood in order that anomalous behaviour can be identified. It should be noted in addition that a study of the seasonal cycle is far from being entirely of academic interest. In some areas of the world, such as S.E.Asia, annual swings in MSL of well over a metre are observed, and the seasonal cycle of MSL plays a large part in coastal erosion (Kibria 1983). In such areas the seasonal cycle is usually similar to or larger than the daily tidal range, and is consequently of major importance in studies of coastline protection and flooding.

All the MSL data in this paper come from tide gauge measurements collected by the Permanent Service for Mean Sea Level (PSMSL 1976,1977, 1978), while data on atmospheric sea level pressure are extracted from 'Monthly Climatic Data for the World' compiled by NOAA. For many stations in the PSMSL database there are simply thirty years more data available now since the Pattullo et al study which allows a more accurate extraction of the parameters of the seasonal cycle. Some stations did not operate prior to 1955, so our knowledge of the global distribution of the seasonal cycle can be widened. Conversely, some stations have ceased operation, although their older data are in most cases still available. With the total data it is possible to provide a better world overview of the MSl seasonal cycle, although there are still deficiencies in the data from ocean islands, at high latitudes and in the Southern Hemisphere.

The main forces driving the MSL seasonal cycle have been known for many years. At mid-latitudes these are primarily the temperatures in the upper layers of the oceans providing a peak in MSL in late summer, together with, at high latitudes, changes in sea level pressure (SLP) peaking MSL in winter. In tropical areas, such as the Equatorial Atlantic Ocean, the seasonal variation of heat content (which is not confined to the upper layers and comes primarily from advection rather than insolation) is a major forcing. There are, however, many other factors (such as the influence of coastal currents or river runoff) which locally can be of equal or greater importance (Pattullo 1963).

At any one particular tide gauge station the MSL seasonal cycle is usually simply described as the sum of an annual cycle (Sa) and a semiannual cycle (Ssa). The Sa-Ssa designation follows the conventional notation for long period tides, although the astronomical contribution to the MSL seasonal cycle is small (Pattullo et al 1955, and see below). The semiannual component can be of equal importance to the annual term in tropical areas where MSL, ocean currents, temperatures and winds are all semiannual in character. However, a large Ssa does not necessarily imply a realistic six-monthly oscillation, but could be the result of irregularities in the seasonal cycle caused, for example, by the sudden onset of the Monsoon. At mid- and high-latitudes the amplitude of the semiannual component is usually an order of magnitude lower than that of the annual.

Once the amplitude and phase of each component has been determined for every tide gauge station in the world, it is possible, in principle, to draw 'cotidal charts' as a presentation of their worldwide distribution. This has recently been attempted for the Pacific by Wyrtki and Leslie (1980) and the present paper extends this study to all the world's oceans. The parameters of the seasonal cycle in a particular area may show considerable differences from gauge to gauge which can only be understood at a local level where maximum information on currents, temperatures, SLP and winds can be collected. It is clear, therefore, that such worldwide 'cotidal charts' are merely capable of showing the gross features of the MSL seasonal cycle.

However, along the oceanic coastlines of the Northern Hemisphere there are copious tide gauge data available which enable a more detailed study of the main components of the MSL seasonal cycle.

2. The Data

The database of the PSMSL contains monthly values of mean sea level from over 1000 tide gauge stations. The 390 which have been used in this analysis are listed in three groups in Tables 1-3. These three groups comprise:-

Group 1 (259 stations) - stations with at least 20 years of data and with controlled benchmark datum stability (i.e. which appear in the 'Revised Local Reference' series of the PSMSL).

Group 2 (79 stations) - stations with at least 20 years of data but without the datum stability requirement.

Group 3 (52 stations) - stations with less than 20 years data but which are of interest owing to the scarcity of other tide gauge data in the geographical area.

The remaining stations in the database are in general of short record length, situated nearby to better quality data, and have not been included in this analysis. A large fraction of them come from Japan and the Americas which are already well represented in Groups 1 and 2.

The requirement of at least 20 years data for Groups 1 and 2 has been made in order to reduce to a low level the inter-annual fluctuations in the data which are present for all stations but especially for those at high latitudes and stations in the Pacific which contain strong 'El Nino' signals. Longer period ocean tides can, in principle, also distort the seasonal signal if short record lengths are used. However, even the most important of the long period tides for this study, the 'pole tide' with approximate period 14 months (Maksimov in Lisitzin 1974, Thompson 1980, Cartwright 1983), will have only a minute contribution to the seasonal cycle parameters if at least 20 years of data are required. No attempt has been made in this report to subtract from the MSL data any estimate of the contribution from long period tides.

The shorter record length stations of Group 3 clearly fail the stringent 20 year requirements of Groups 1 and 2. They have been included in this analysis only when there is not a reasonable amount of better quality data from Groups 1 and 2 in the geographical area.

3. Extraction of the Seasonal Cycle Parameters

The amplitude and phase of the annual (Sa) and semiannual (Ssa) MSL cycles are obtained by harmonic analyses of the monthly values of MSL. The suitability of parameterising the monthly values for each station as the sum Sa + Ssa will be discussed below for particular stations. However, for most stations around the world this parameterisation appears to be an adequate one.

In the case of Group 1 stations two methods have been used to obtain the Sa and Ssa parameters. Method 1 comprises a multiple regression least squares fit to the monthly MSL values (MSL(M)) of the form:

$$\mathrm{MSL(M)} = a_0 + a_1 t + \mathrm{ASA} \cos\left[\frac{2\pi}{12}(t - \mathrm{PSA})\right] + \mathrm{ASSA} \cos\left[\frac{2\pi}{6}(t - \mathrm{PSSA})\right]$$

where 'M' is the time in months from the beginning of the first year of the station record (M=1 for January of the first year) and

$$t = M - 0.5$$

accounts for MSL(M) being an average for month M. The linear term 'a1 t' provides an approximation of the secular trend of MSL at that station while 'ASA' and 'ASSA' are the amplitudes of the annual and semiannual cycle respectively, and 'PSA' and 'PSSA' are the phases (in months). Note that PSA is the number of months from the beginning of the year to the time at which the annual cycle is a maximum. Similarly, PSSA (and PSSA + 6 months) is when the semiannual cycle peaks.

The choice of defining the phases of the cycles in this way is more convenient in the present study than the usual tidal theory convention for the phase lags (G) of Sa and Ssa to be zero at the mean vernal equinox when the declination of the 'mean sun' is zero and increasing (Doodson and Warburg 1941). The values of G can be obtained from those of PSA and PSSA via

$$G(Sa) = 30\ PSA - 80$$

$$G(Ssa) = 60\ PSSA - 160$$

where PSA and PSSA are in months as above and the G values are in degrees.

Information on each station and the results of the regression fits are shown in Table 1. Besides latitude and longitude, the Table shows the number of years of available data and the range of years for which data exists. Note that within each range there may be a number of years of missing data which tide gauge benchmark information has to span before the Method 1 fit can be made. The fit quantities (ASA,ASSA,PSA,PSSA) and the standard error (Δ) of the amplitudes ASA and ASSA are also listed. The standard error on the phases can be simply obtained via

$$\text{error on PSA} = (\Delta / ASA) \times 12/2\pi$$

$$\text{error on PSSA} = (\Delta / ASSA) \times 6/2\pi$$

The final column in Table 1 shows the residual standard deviation in the data (σ) after the fit. This residual jitter has many components both long period (e.g. imperfections in the linear description of the MSL trend) and short period (e.g. from variations in the seasonal cycle or from monthly MSL fluctuations). In general, σ increases towards higher latitudes.

For purposes of comparison with the results of Wyrtki and Leslie (1980), note that the similar parameter (also called σ) is larger in their case as the linear MSL trend was not included in their regression formula.

In order to make the above regression the tide gauge datum stability provided by the 'Revised Local Reference' of the PSMSL is an essential precondition. Method 2, which does not require year to year datum stability (although stability within a year of data is assumed), is necessary to make use of the many long record length stations in Group 2, and those in Group 3. For each month 'j' (j=1,12), an average of the monthly means from the 'N' years of available data is computed:

$$\mathrm{AVG}(j) = \frac{1}{N}\sum_{i=1}^{N} \mathrm{MSL}(j,i)$$

where 'MSL(j,i)' is the monthly mean sea level for month j and year i. Simple extraction of the coefficients of a Fourier expansion of the AVG(j) yields the parameters of the seasonal cycle. This is equivalent to Method 1 omitting the sea level secular trend term from the regression, and gives the same results as the procedure used by Wyrtki and Leslie (1980) in their analysis of Pacific stations.

The omission of the secular trend in Method 2 introduces a very small distortion in the parameters obtained for Sa and Ssa. In Method 2, a +10mm/year trend in MSL uniform throughout the year is interpreted as an annual cycle of amplitude 3.2mm (peaking in month 9.0) and a semiannual cycle amplitude 1.7mm (peaking in months 4.5 and 10.5) which add to the 'real' seasonal cycles. However, for most of the world the MSL trend is typically only 1-2mm/year (Barnett 1983), and for most stations this is therefore not a serious bias.

All stations from Groups 1,2 and 3 were subjected to analysis by Method 2. In the case of Group 1, the results obtained, although virtually identical to those obtained via Method 1, are considered marginally less reliable and have not been included in Table 1. The Method 2 results for Groups 2 and 3 are shown in Tables 2 and 3. The standard error (Δ) is obtained in the same way as Wyrtki and Leslie (1980):

$$\delta^2 = \frac{1}{12} \sum_{j=1}^{12} (\mathrm{AVG}(j) - \mathrm{CALC}(j))^2$$

where 'CALC(j)' is the value for month j determined from the parameters of the Fourier expansion and

$$\Delta = 0.5\ \delta$$

The final column in Table 1, the residual error from the regression fit in Method 1, has no counterpart in Method 2 and is not present in Tables 2 and 3.

The stability of the parameters in Tables 1-3 with respect to long term fluctuations in the seasonal cycle has been investigated by sub-dividing the data from stations with long record lengths. Of all the long period stations we have investigated, there is no large observed drift with time in the seasonal cycle parameters. A possible exception might be San Francisco which shows some evidence (at the three standard deviation level) of an annual amplitude between the years 1937-1980 approximately twice that for 1855-1895. The variability of the data for San Francisco is discussed further below.

The stability of the parameters with respect to bad measurement or other unknown bias can be estimated to some extent from those ports in

Tables 1-3 which contain two tide gauges (Newcastle, Sydney and Adelaide in Australia; Coruna, Aberdeen, Liverpool and Split in Europe) and the continuity of the data between adjacent ports in progressing along a regular coastline. In general, the self-consistency of the data is excellent.

4. Discussion of the Seasonal Cycles in the Northern Hemisphere and in Tropical Areas

We now turn to a discussion of the main features of the seasonal cycle along the four main oceanic coastlines in the Northern Hemisphere (Europe, Eastern and Western America and Asia) from which the bulk of the data on MSL originates. The four offer different degrees of complexity in understanding the seasonal cycle. Both American coastlines are regular with few indentations, off-shore islands or large expanses of continental shelf. The compatibility of the results of one tide gauge with those of its neighbour along the coast is usually very good. The European coastline is less regular and contains a considerable extent of shallow continental shelf in the North and Celtic Seas. Full understanding of the seasonal cycle in such conditions is only possible through extensive computer modelling of the effects of the various meteorological factors. The 'Asian' coastline we have attempted to contruct with data from the USSR, Korea, Japan, China and the Philippines. This 'coastline' is hardly regular and there is considerable variation including 'Northern European' type cycles in the USSR through 'Monsoon' conditions in southern China to the 'tropical cycles' in the Philippines. This area has been studied relatively little in spite of containing approximately 20 percent of the tide gauge stations in the PSMSL database (most of them from Japan). The geographical breakdown of the data into the four Northern Hemisphere coastlines omits discussion of modern studies of the tropical oceans. Research into the seasonal cycle of MSL in tropical areas is briefly summarised after the four sections on Northern Hemisphere coastlines.

a. Europe

The amplitude and phase of the annual and semiannual MSL cycles in Europe, using data from Group 1 stations, is shown in Figs.1 (a)-(d) versus latitude. This data spans from Russkaya Gavan (in Novaya Zemla which we consider nominally part of the European coastline) to Tenerife in the south. Fig.1 also includes Reykjavik and Barentsberg but excludes data from the Baltic and Mediterranean. The annual cycle in northern Europe is seen to be approximately constant in phase (Fig.1(b)) as far south as 45deg N (except for an anomalous value at Oslo 60deg N which is more like the Baltic stations, see below) peaking in mid- November. The decrease in amplitude in the south is one consequence of the reduction of the contribution from sea level pressure (SLP) and winds on MSL. This is demonstrated in Figs.2 (a)-(d) which show the annual and semiannual contributions to MSL from SLP alone using the Isostatic Relationship (Pattullo et al 1955) and adjusting the phases (Figs.2 (b) and (d)) to refer to the peak time of MSL from this effect. (We ignore a small correction to the SLP contribution from the seasonal fluctuation in the average pressure over all the oceans (Pattullo et al 1955)). Note again the anomalous Oslo annual phase in Fig.2 (b). At high latitudes SLP alone is responsible for 40-50 percent of the seasonal cycle of MSL, a percentage which decreases with decreasing latitude. South of 45deg N the phase of the annual component of the SLP contribution increases rapidly (Fig.2(b)) which explains the small increase in the phase of the MSL annual cycle at this latitude (Fig.1(b)). South of this point, however, the amplitude of the SLP contribution is only about 20 percent of the total MSL annual cycle and the resulting phase of the MSL annual cycle, in southern Spain, Portugal and Tenerife, becomes more like that expected for the (mostly steric) oscillations of the Atlantic (Pattullo et al (1955), Gill and Niiler (1973)). The rapid change of phase of the SLP contribution at around 45deg N is a consequence of a 'nodal point' in a distribution of the seasonal cycle of SLP situated off northern Spain and discussed by Lisitzin (1974).

For most of the European coastline the semiannual MSL cycle (Figs.1(c)-(d)) is considerably less important than the annual except around southern Portugal where a 'Mediterranean cycle' asserts itself (see below). The semiannual cycle is everywhere 'real', however, in the sense that its amplitude is larger than the statistical error and that its phase is well determined and smoothly varies from station to station (Fig.1(d)). The SLP contribution to the semiannual MSL cycle (Fig.2(c)-(d)) is probably of more relative importance than in the case of the annual cycle. At the extreme northern and southern latitudes the amplitudes of the SLP contribution (Fig.2(c)) are comparable to those of MSL (Fig.1(c)) and are in phase with it

(Figs.1(d),2(d)). As with the annual term, the phase of the SLP semiannual contribution undergoes the largest change around 50deg N (close to the 'pressure nodal point' of Lisitzin (1961)).

The average monthly values of MSL shown in Figs.3 (a)-(g) illustrate the results of Figs.1 (a)-(d). The strong annual cycle apparent at Murmansk and Tromso is modified by a shoulder in mid-year resulting in the semiannual phase at around month 0.0 (or 6.0). In the south (for example, Cascais 38deg N) the seasonal variation is almost absent except for a short rise at the end of the year. The role of the semiannual term here is to cancel the depression the annual cycle would create in late April or May. The origin of the increasing relative importance of the semiannual cycle of MSL and its change of phase in a southward direction along the European coastline can thus be seen.

The two large European inland seas, the Mediterranean and the Baltic, have similar seasonal cycles to adjacent stations on the Atlantic coast. Most stations in the western Mediterranean behave in much the same way as Cascais on the Atlantic coast (Tables 1-3). In this area of the Mediterranean most of the seasonal MSL cycle comes from density variations (Palumbo and Mazzarella 1982). At the eastern end (Izmir, Antalya and Port Said) the annual cycle peaks about 2 months earlier. Throughout the Mediterranean a semiannual amplitude around 30mm is present peaking around early May (and November) at the western end and in January (and July) in the east. The seasonal cycle for the 44 Baltic stations in Group 1 are summarised in Figs.4 (a)-(d). The annual cycle has approximately the same amplitude as for neighbouring stations on the Atlantic coast but the phase is one month earlier. The semiannual cycle has, on average, a considerably larger amplitude than for the Atlantic and peaks about one month later. The Baltic has been discussed extensively in the literature (Lisitzin 1974 and references therein).

The fact that the phase of the annual cycle (Fig.1 (b)) along the European coast from 50deg N to 80deg N is essentially constant while its amplitude increases by a factor of three is primarily a consequence of the meteorological contributions to the cycle (SLP (Figs.2 (a)-(b)) and winds) having a similar phase over much of the coastline but being considerably weaker in the south. The total meteorological contributions to the annual cycle are, in principle, straightforward to estimate with the help of numerical models (Davies 1983, Thompson 1980) as the important factors (SLP, winds, bathymetry etc.) are all well recorded. In the area of the N.W. European continental shelf, their effect is to produce a small contribution to the annual cycle in the English Channel and southern North Sea but a maximum contribution (around 80mm in amplitude) off the north of Scotland and in the German Bight (Davies 1983). To some extent these features can be seen in the measured amplitudes listed in Tables 1-3 and displayed in Fig.5. In the south, amplitudes of around 40-50 mm are observed (e.g. Newlyn or Brest). The amplitude of this 'residual cycle' which is itself roughly in phase with the meteorological factors, is comparable to seasonal oscillations in steric levels observed many years ago for the North Sea, Bay of Biscay and Station K (off La Coruna) (Pattullo et al 1955, Thompson 1980) as well as that thought to be the oscillation for the adjacent North Atlantic (Gill and Niiler 1983). Unfortunately, there are no modern analyses of steric levels extrapolated to the tide gauge positions on the coast.

Table 4 compares the amplitude and phase of these 'steric' or 'residual' contributions to the annual cycle of MSL estimated in various ways. Row (a) of the Table shows the parameters of the annual cycle for islands in the Atlantic and for Newlyn after the removal of the SLP contribution. Note that the values for the Cape Verde Islands are based on only four years of data. The contributions from winds and other effects have been disregarded. These Newlyn parameters are virtually identical to those obtained in a more extensive analyses of Newlyn MSL (Thompson 1979, Cartwright 1983). Row (b) shows the annual cycle of steric height taken from Pattullo et al (1955), the 'Newlyn' column containing an average of the data from Station K and the Bay of Biscay. The steric height values for the North Sea are shown in the final column and can be seen to be very similar to those for the reduced Newlyn tide gauge values.

Row (c) of the Table shows the prediction of the model of Gill and Niiler (1973) for the annual cycle of steric heights (see their Fig.3). The prediction for Tenerife has been made by extrapolating slightly outside their model grid. Included in the 'Newlyn' column are the predictions for box 15-20W/50-55N which is close to the area of the Pattullo et al steric height measurements. A comparison of the different rows of Table 4 might suggest that there is reasonable agreement between model and data over the whole ocean but that the amplitudes in the east are possibly underestimated. The phases of the model at 'Newlyn' and in the Azores agree better with the reduced tide gauge data in row (a) than do those of the meagre steric height data. This is acceptable if the phase changes by only small amounts over the whole ocean.

The conclusion therefore for the annual cycle of MSL in this region is that the average cycle over much of the ocean and complicated areas of continental shelf can be modelled (and thereby understood) successfully.

The semiannual cycle of MSL also includes contributions from steric oscillations. The data of Pattullo et al (row (e) of Table 4) show an amplitude of about 6mm for 'Newlyn' (the average of Biscay and Station K data) peaking at the beginning of April. This is similar in phase and amplitude to the reduced Newlyn tide gauge values obtained both in this analysis (row (d)), in that of Cartwright (1983), and to those obtained for other stations around the UK (Thompson 1980). Bermuda and the Azores both contain SLP corrections to the semiannual MSL signal comparable in size to the observed tide gauge values. They are therefore not included in row (d) in view of additional uncertainties such as winds. Tenerife and the Cape Verde Islands semiannual MSL data are probably consistent with being in phase with the 'Newlyn' measurements and a peaking over the whole ocean around April. Unfortunately, the work of Gill and Niiler (1973) does not allow a model comparison as for that with the annual cycle as their results are presented merely for each of the four seasons and a semiannual component is not extractable.

Although the *average* European seasonal cycle discussed above is well determined from the copious amount of tide gauge data available, and considerable progress has been made in understanding its components, an examination of the data from any station reveals that the seasonal cycle is not in the least regular from year to year. With all contributions to the cycle (SLP, winds, heating etc.) roughly in phase, a question arises as to which factor is the main source of the seasonal cycle variability. The average MSL seasonal cycle can be represented by the average monthly mean values (AVG(j) as defined above) with a common factor removed such that

$$\sum_{j=1}^{12} AVG(j) = 0$$

The seasonal cycle for a particular year is shown by MSL(j,i) again reduced such that

$$\sum_{j=1}^{12} MSL(j,i) = 0 \quad \text{for all } i$$

and the 'Relative Strength' ('V') of the seasonal cycle for the year 'i' measured by

$$V(i) = \frac{1}{f^2} \sum_{j=1}^{12} MSL(j,i) \times AVG(j)$$

$$\text{where} \qquad f^2 = \sum_{j=1}^{12} AVG(j) \times AVG(j)$$

The average value of V(i) is 1.0 while larger or smaller values of V(i) represent a stronger or weaker seasonal cycle for the year 'i' respectively. The factor 'f' in the denominator is roughly proportional to the amplitude of Sa if stations with seasonal cycles predominantly annual in character are studied. The quantity 'V' can be computed for all years of the MSL seasonal cycle, and for all the contributors to the cycle. Fig.6 (a) shows the variation of V for Aberdeen MSL. The average is 1.0 and the standard deviation (which we call the 'normalised variability' (v)) is 0.29. The 'normalised variability' for SLP at the same location (Fig.6 (b)) is approximately 2.5 larger than that for MSL, and V(MSL) is moderately well correlated with V(SLP) (correlation coefficient 0.51). Because the average SLP contribution to the average MSL seasonal cycle (f(SLP)/f(MSL)) is only 0.3 but 'v' for SLP is 2.5 times larger than 'v' for MSL, SLP can be considered to contribute to an amount R = 0.3*2.5 = 0.8 of the seasonal variabilty of MSL.

Table 5 compares the relative importance of SLP to the average MSL seasonal cycle via the ratio f(SLP)/f(MSL) and the ratio of the amplitudes of the annual cycles Sa(SLP)/Sa(MSL) for stations along the European Atlantic coast and for Reykjavik and Horta (Azores) in the Atlantic. Because most of the MSL and SLP cycles are annual (with the exception of Oslo) the two ratios are very similar. For most of the European coastline the SLP variation is only around 20 percent, as has been shown already above in Figs.1 and 2, although the ratio does increase at higher latitudes and for the Atlantic islands. The role of SLP alone in southern Norway and Denmark is extremely small. The third column of Table 5 shows the difference in phase (in months) between the annual cycles of MSL and SLP. If the phase difference is large, one would not expect SLP to be the major contributor to the average MSL seasonal cycle, although it could be the major contributor to its variability. While SLP, therefore, is never the only contributor to the average value of the MSL seasonal cycle, the quantity 'R' in the fourth column of Table 5 shows SLP to be the major (and maybe only) contributor to its variability in Reykjavik and northern Britain.

A value of R of 0.71 = sqrt(0.5) is the limit for which we can say that SLP is the major contributor to the variability; below this value other quantities added in quadrature will be of equal or greater importance. SLP at Newlyn, therefore, with R=0.72 can still just be considered the major contributor. Thompson (1979) in fact managed to represent monthly values of MSL at Newlyn as a combination of a fixed annual and semiannual cycle together with SLP and wind factors explaining in this way over 90 percent of the MSL variance. The fact that this was possible implies that the steric oscillations (which comprise a large part of the annual and semiannual terms) are essentially stable. Rossiter (1962) also expressed the view that year-to-year variations in steric levels in this area are insignificant. Most of the additional variability at Newlyn not explained by SLP in Table 5 can therefore be accounted for by winds in a prescription such as that of Thompson (1979). South of Newlyn other factors than SLP have to be invoked to explain MSL seasonal cycle variability and it is likely here that steric oscillation variability does become important. Along the southern Norway coast (Bergen,Oslo) the SLP contribution is also low although it is possibly of greater importance to the MSL seasonal cycle variability than to the average MSL seasonal cycle itself.

b. Eastern North America

The seasonal cycle of eastern North American MSL from the Gulf of Mexico to Canada are considerably different in character from those discussed in Europe; the main feature being the equal importance of the annual and semiannual cycles along the entire coastlines.

Figs.7 (a)-(d) and 8 (a)-(d) show the amplitudes and phases of the seasonal cycle for the Gulf of Mexico (versus degrees West) and for the Atlantic coast (versus degrees North) respectively. In the Gulf of Mexico the seasonal cycle changes from being predominantly semiannual in character in the west to mostly annual between New Orleans and the tip of Florida. The phases of both cycles are fairly stable; the semiannual phase in particular varies by only 12 days across the entire Gulf. At the turn into the Atlantic at Key West the transport of the Florida Current reintroduces the strong semiannual component of the MSL variation (Montgomery 1941).

The plots of average monthly MSL (Figs.9 (a)-(h)) emphasise the clear semiannual character of the seasonal cycle in the western Gulf of Mexico (Port Isabel to Bayou Rigaud). This is considerably more obvious than in the plots for Cascais (Fig.3(f)) and Mediterranean stations discussed above, where a strong semiannual component is also obtained from the harmonic analysis, but which is not so immediately obvious in the data. On the Atlantic coast, from Key West to the Canadian border, the seasonal cycle remains a mixture of the annual and semiannual (Figs.8 (a)-(d)). Although the amplitudes for both cycles jitter to some extent about a decreasing trend when travelling north, the phases of the two cycles are remarkably well reproduced from station to station. This suggests that the factors which would introduce instability from station to station in the observed average seasonal cycle (e.g. river runoff) are of minor importance along this coastline, although in this area variation in river runoff in particular is thought to account for as much as 21 percent of the interannual variation in MSL (Meade and Emery 1971). Note that the anomalous semiannual amplitude and phase at 38deg N comes from Richmond which is a considerable distance up the James River from the sea. In addition, Richmond and St.John N.B. have annual phases off the scale in Fig.8(b) (see Table 1). The six stations between 37 and 40deg N with annual amplitudes over 80mm all lie inside the Chesapeake or Delaware Bays. The annual phase progressively moves earlier in the year going north until at around Cape Cod (42deg N) a clear change of phase takes place to the winter peaking expected of stations at high latitudes.

The semiannual cycle (Figs.8 (c)-(d)) also decreases smoothly in amplitude from a maximum at Fernandina to essentially nothing at the Canadian border. The few stations north of 45deg N show non-zero amplitudes once again but by this time the phase has changed from that of around 3.5 months, typical of the Gulf of Mexico and most of the Atlantic coastline, to around 6.0 typical of the higher latitudes of northern Europe. This phase change takes place smoothly between Cape Cod and Nova Scotia (Fig.8 (d)).

One of the main components of the MSL seasonal cycle along the Atlantic coast, if not the dominant one, is the variation of the Florida Current and the Gulf Stream system, with Cape Cod regarded as the northern limit of their influence. This topic has been reviewed by Fofonoff (1981) and we confine ourselves here to factors influencing the seasonal cycle. Montgomery (1937) made one of the first studies of the monthly sea level on the eastern coast of the USA discussing the relative importance of onshore wind (in the Savannah-Charleston area), river runoff, thermal and atmospheric effects and changes due to fluctuations of the gradient currents. By subtracting the monthly MSL average for Charleston from that at Bermuda an estimate of the fluctuations of the average surface currents could be obtained. This quantity contains a clear semiannual component.

Fuglister (1951) studied the average speed in the Gulf Stream system along the US coast from Florida to Cape Cod. His results, reduced to their annual and semiannual components, are shown in Table 6. The speed of both components decreases by about a factor of four going north, the ratio of the amplitude of the semiannual component to that of the annual being about 1/3 throughout which is not unlike that for MSL. However, while the phase variation of the semiannual cycle is very similar to that for MSL (Fig.8(d)), the phase of the annual cycle peaks about 2 months later in the year than does the MSL annual phase (Fig.8(b)) and changes only by about 1 month from south to north compared to 2 months for MSL. It is impossible therefore that the Gulf Stream variation is the only factor influencing MSL along the Atlantic coast.

Chase (1979) showed that in the Mid-Atlantic Bight (around 40deg N) a regression of MSL against Gulf Stream Position (GSP) still showed a good correlation (GSP being in turn related to Gulf Stream speed following a proposition of Iselin (1940)) in spite of the additional importance of other factors such as density or winds. In fact, the longshore pressure gradient in this area was found to depend almost entirely on the coastal east-west wind. The values of GSP used by Chase were taken from Fuglister (1972) and again show a ratio of 1/3 for the semiannual to annual amplitudes. The annual signal peaks at month 9.5, roughly agreeing with the northerly values in Table 6. The semiannual phase is at month 4.6, rather different to those of Table 6 and to those expected from MSL. However, as the Fuglister (1972) GSP variation is based on one year's data only, the weak semiannual component is probably not reliably measured.

A second factor in the MSL seasonal cycle is the role of sea level pressure (SLP). The SLP contributions are shown in Figs.10(a)-(d) and 11(a)-(d) for the Gulf of Mexico and Atlantic coasts respectively. Throughout most of the Gulf and the southern part of the Atlantic coast, amplitudes of the SLP contributions to the annual and semiannual MSL cycles are 4 or 5 times lower than the MSL cycles themselves. Progressing north, however, the SLP annual contribution becomes relatively more important and peaks earlier in the year until, north of Cape Cod, the SLP term is comparable to that of MSL and peaks around March. The annual SLP term can therefore be seen as a compensating factor to the slower phase variation of the annual Gulf Stream influence in reproducing something like the observed annual MSL values.

The semi annual SLP term meanwhile is roughly in phase both with the observed MSL semiannual term and with the semiannual component of the

Gulf Stream speed. North of Cape Cod, however, its phase changes very quickly and it is no doubt a major contributor to the similar change of phase of the semiannual component of MSL.

The role of winds in the seasonal MSL cycle along the Atlantic coast is less well documented, although data sources of seasonal wind stress do exist (Saunders 1977). Over a short distance in the Mid-Atlantic Bight, Chase (1979) showed that coastal east-west wind was the major factor in the longshore pressure gradient. Sturges (1974) remarks on the modification of the MSL seasonal cycle in Florida by winds blowing against the coast in late autumn and changing direction in different seasons. The instantaneous wind field over the Atlantic can be calculated from surface air pressure maps (Thompson and Hazen 1983), and further modelling of the MSl seasonal cycle using such data would no doubt be worthwhile.

c. American Pacific Coast

The seasonal cycle of MSL along the eastern edge of the Pacific is shown in Figs.12 (a)-(d). Stations from Groups 1,2 and 3 have been included in order to be able to study the cycle the length of the longest north-south coastline in the world; most of the data south of the equator come from Groups 1 and 2. Our results along the whole American Pacific coast (and for the rest of the Pacific) agree well with those obtained by Wyrtki and Leslie (1980).

MSL in the north east Pacific is probably the most studied in the world. In 1939, La Fond demonstrated the close correspondence between steric height and tide gauge measurements in central and southern

California where meteorological factors are less important than at higher latitudes. North of 40deg N, however, the correlation between the MSL seasonal cycle after correction for SLP, and the steric height cycle of the mid-Pacific (Pattullo et al 1955, Wyrtki 1974) was known to be poor, the tide gauge measurements having a seasonal high in winter (Nov-Feb) and the mid-Pacific steric level cycle peaking in late summer. Reid and Mantyla (1976) showed this difference to be a consequence of the subarctic cyclonic gyre of the north Pacific ocean. Steric heights measured closer to the coast were found to correlate well in most cases with the tide gauge MSL measurements. (Note comments on Reid and Mantyla (1976) in Csanady (1979)). The steric height data of Reid and Mantyla have been used further recently by Hickey and Pola (1983) to study the seasonal cycle of sea level slope along the same coastline.

The residuals of MSL from the average seasonal cycle at each station show a considerable amount of interannual activity that is now closely identified with the El Nino 'warm events' in the Pacific. This interannual activity has been discussed, for example, by Enfield and Allen (1980), Thomson and Tabata (1981) and Chelton and Davis (1982). It is conceivable that this activity distorts the calculation of the parameters of the seasonal cycle from those which would be appropriate for 'normal' years. Using the data from San Francisco, each year between 1930 and 1930 was defined as a 'positive (or negative) anomaly' year if the MSL residual for that year after the regression of Method 1 was positive (or negative). For example, the major El Nino years of 1957-58, 1969-70 and 1972-73 are included in the 'positive anomaly' years. Recalculating the parameters of the seasonal cycle for positive or negative anomaly years only gives the results shown in Table 7. In each case there are about 20 years of data so the statistical error on the determined quantities is small. For 'all years' (1930-1980) the parameters of the seasonal cycle for each station are essentially those of Tables 1 with the exception of San Francisco which has a larger annual amplitude as discussed above. The amplitudes of Sa for positive anomaly years are marginally larger for obvious reasons. The annual phase for stations which are predominantly annual in character (Sitka, Prince Rupert, Neah Bay and San Diego) is almost unchanged while stations which contain a large semiannual component (Crescent City and San Francisco) have a change of annual phase of around a month. The semiannual amplitudes for all stations are changed on average by less than a third while the semiannual phase is distorted by about a quarter of a month. This comparison of 'positive' and 'negative anomaly' years, therefore, can be regarded as an estimate of the systematic errors involved in the determination of the average seasonal cycles.

The averaged annual component of the seasonal cycle is shown in Figs.12 (a) and (b). Note that the value for Guaymas (in the Gulf of California) is off-scale in Fig.12(a) (see Table 3). In the northern American Pacific the annual cycle peaks later in the year as expected for stations at high latitudes dominated by meteorological factors. The main features of the annual cycle of SLP (Figs.13(a) and (b)) can be clearly seen in the MSL cycle. North of 50degN the SLP contribution amplitude approaches 60mm dropping to lower values between 40 and 50deg N where a 'pressure nodal point' discussed by Lisitzin (1961) is situated. South of this position the annual SLP amplitude increases again to around 20mm and changes its peak time to be roughly in phase with the mid-summer peaking of the ocean steric heights. The latter clearly dominate over SLP at these latitudes as can be seen from the relative size of the observed MSL amplitudes over those from SLP. Note that seasonal cycle parameters for Astoria (46deg N) in all four Figs.12 (a)-(d) appear anomalous, a large contribution to its seasonal cycle coming from Columbia River runoff (Chelton and Davis 1982).

The seasonal cycle along the South American Pacific coast is considerably less studied than those in the north (Enfield and Allen 1980). Figs.12 (a) and (b) show that the amplitudes of both the annual and semiannual cycles are on average less than those in the Northern Hemisphere stemming from the weaker influence of SLP (Figs.13 (a)-(d)) and surface layer temperature (Wyrtki and Leslie 1980). All stations along the South American Pacific coast lie north of 40deg S, and have a peak in the MSL seasonal cycle in their own late summer in a similar way to the Californian stations. The rapid change of phase of the annual cycle at the equator (Fig.12 (b)) from a 'Northern' to a 'Southern Hemisphere' phase, and the generation of a large semiannual amplitude in the region (Fig.12 (c)-(d)), can be better understood by an inspection of the average monthly MSL values shown in Figs.14 (a)-(h). Starting at the mainly annual in character variation at Los Angeles, the MSL distribution for September onwards flattens off until, at Buenaventura, a decrease of MSL only around March can be seen. This behaviour, which generates also the large semiannual component, is thought to be a consequence of variations in the N.E. trades (Enfield and Allen 1980). At La Libertad there is almost no seasonal cycle at all. South of the equator, the seasonal cycle is purely annual with a peak around March, as expected for the Southern Hemisphere. Further detailed discussion of MSL off the Mexican coast has been made recently by Enfield and Allen (1983). A similar change of phase at the equator is also evident in the annual contribution from SLP (Fig.13 (b)) although the amplitude of this term in this region is extremely small (Fig.13 (a)).

The amplitude and phase of the MSL semiannual cycle are shown in Figs.12 (c)-(d). The largest amplitudes occur off the coast of Central America as discussed above. In the Southern Hemisphere, the semiannual amplitude is only sizeable south of 30deg S where, although it is considerably larger than the SLP contribution (Fig.13(c)), it is roughly in phase with it (Fig.13(d)). North of 20deg N, while the MSL semiannual amplitude is extremely variable (Fig.12(c)), in certain regions (between 30 and 40deg N and north of 50deg N) it is comparable to and in phase with the SLP contribution alone (Figs.13(c)-(d)). Note that the amplitude of the SLP contribution is close to zero around 50deg N as for the SLP annual contribution. A detailed investigation of the role of SLP and winds along the North American Pacific coast can be found in Enfield and Allen (1980).

d. Asia and the Central Pacific

The amplitudes and phases of the seasonal cycles from Asian stations in Group 1 are shown in Figs.15(a)-(d). The vast majority of these data come from Japan following the interest in this area in the use of tide gauges as part of a tsunami warning system. Of the nine stations on the Asian mainland, one is in Korea, 3 in the USSR and 5 in China. The Asian 'coast' is represented in the south by geographically diverse stations from the Philippines. Note that stations on the mainland in China and Korea and those on the west coast of Japan were not included in the Pacific compilation of Wyrtki and Leslie (1980).

Of the three USSR stations in the north west Pacific, Petropavlovsk (53deg N) on the Pacific side of the Kamchatka peninsula, has an annual phase and amplitude similar to those for stations on the northern Pacific coast of America. A relatively large semiannual contribution is present also. This is almost certainly a consequence of the changing circulation in the area throughout the year, as discussed by Reid and Mantyla (1976). This station has typical 'high latitude' SLP contributions (Figs.16(a)-(d)) especially in the phase of the annual SLP contribution (Fig.16(b)). The other two USSR stations, Nagaeva Bay which is situated in the north of the Sea of Okhotsk and Yuzhno Kurilsk which is close to the north of Japan, have annual phases (and SLP annual phases) more typical of stations to the south even though their MSL annual amplitudes are somewhat lower. These two stations also contain sizeable semiannual MSL components roughly in phase with the SLP semiannual contribution.

The north-south difference of the seasonal cycle in Japan is clearly demonstrated by the copious amount of data available. The most striking feature is shown in Fig.15(d) where a sharp difference in MSL semiannual phase is apparent between stations in the north (in Hokkaido and both sides of Honshu) and those in the south (in Kyushu, Shikoku and the Inland Sea area of Honshu). The southern stations also have smaller semiannual amplitude but very large annual amplitudes. The latter are partly a consequence of the large annual SLP contribution in the south (Fig.16(a)). The phase of the annual cycle is much the same for all stations. This behaviour is confirmed by the few Japanese stations in Group 2 in which the only station with semiannual phase in March is Fukabori in Kyushu. The MSL seasonal cycle on the Pacific coast of Japan will be influenced to some extent by the variations of the Kuroshio current system (Mizuno and White 1983) in an analogous way to stations near the Gulf Stream. The enormous amount of tide gauge data from Japan would no doubt repay further investigation.

The changes in phase observed in Japan (Figs.15(b) and (d)) are approximately reproduced by stations on the mainland. In China, however, the phase of the annual cycle goes against the general trend and becomes later in the year in the south as the cycle changes from its 'Pacific' character to one more typical of the 'Monsoon' stations in S.E.Asia. Stations in northern China have a predominantly annual MSL seasonal cycle (note that the annual amplitudes for Yantai and Qinhuangdao are off-scale in Fig.15(a) - see Table 1), while the three stations in southern China (Macau, North Point and Xiamen) have strong semiannual components. These and other features of the seasonal cycle in China have been discussed by Zheng and Zhao (1983).

The five stations in the Philippines complete the Asian 'coastline' in the south. Their annual amplitudes and phases are much the same as to be found at the same latitude on the eastern side of the Pacific (Figs.12(a)-(b)). The semiannual components, however, are considerably different in phase from stations on the American coast. Further references to sea level in the Western Pacific and Indonesia are given in Wyrtki (1961), Lisitzin (1974) and Wyrtki and Leslie (1980).

e. Tropical Areas

The seasonal cycle of mean sea level in the eastern tropical Atlantic is represented in Tables 1-3 by only 4 stations from Dakar to Pointe Noire. The annual cycle in this area has been found (Verstraete 1982, 1983) to be significantly correlated with changes in dynamical height and heat content and is consequently primarily steric in character. Heat content variations in this area are primarily caused by advection rather than insolation (Merle 1980) and are of great importance for fisheries via coastal upwelling (Picaut 1983). The semiannual MSL cycle in this area is thought to be in equilibrium with the seasonal cycle of the Guinea Current (Verstraete 1982).

Such tropical MSL changes through variations in heat content also will occur throughout the Indian and Pacific Oceans although in the latter case they will be modified by the 'El Nino' warm events. Sea level in the tropical Pacific has been discussed in Wyrtki (1979) and Meyers (1982). At Truk Island Meyers found the seasonal MSL cycle to be bimodal with a dominant wind-driven semiannual component present in all years (but most apparent in 'normal' years) and an episodic annual signal phase-locked into the El Nino 'warm event' occuring in about one year in four. Our result for Truk Island (Table 1), therefore, is an average of these two distinct seasonal cycles. Research into fluctuations of MSL in tropical areas is of immense current interest with new tide gauge networks planned for installation.

5. Worldwide Summary of the MSL Seasonal Cycle

Figs.17 and 18 summarise the results of the preceding sections on the phases of the MSL annual and semiannual cycles respectively. The figures also include data from stations in the Indian Ocean and the Southern Hemisphere (Tables 1-3) and mark the positions of the tide gauges. It will be noticed that of the total of 390 stations in Groups 1-3 only 64 are in the Southern Hemisphere, and large expanses of the southern oceans are without any data at all.

The worldwide summary in Fig.17 shows 'cotidal lines' sub-dividing our compilation of the annual cycle phase into the four quarters of the year. In the Northern Hemisphere this exercise is obviously a gross simplification of the fine detail in the data discussed above. In the Southern Hemisphere, a certain amount of imagination is required before the lines can be drawn at all. Nevertheless, the main features of the peaking from heating over the oceans in late summer and the meteorological effects at high latitudes in winter are quite obvious.

The overall pattern in the Pacific has been discussed by Wyrtki and Leslie (1980 and references therein). As their analysis included data from more Pacific islands than have been used here, the exact position of the cotidal lines in the southern Pacific have been drawn to be consistent with theirs.

The northern Pacific and Atlantic oceans show great similarities. Both contain major current systems in the west which propagate the summer heating further north and which introduce sizeable semiannual components into MSL. In the north of both oceans the role of SLP becomes paramount. One of the main features of the map is the annual cycle 'amphidrome' over Borneo with the phase of the cycle progressing in an anticlockwise direction. This feature is also present in a distribution of the SLP contribution to the seasonal MSL cycle (Lisitzin 1961) and is a consequence of being a point of stable SLP between the shifting Highs and Lows which produce the Monsoons. The inclusion of the central Indian Ocean within the same cotidal area as S.E. Asia is based solely on three years of data from Diego Garcia, each of which have a different seasonal cycle. Consequently, the cotidal lines in this area have a considerable degree of flexibility. In the southern Indian and Atlantic Oceans, the only data from islands are those from the Falkland Islands and South Georgia. Tide gauges situated at the other islands in the southern oceans (for example, Kerguelen or the Crozet Islands) are required, as are reliable time series from bottom pressure recorders in areas where few islands exist. The three stations in Antarctica have annual cycles considerably smaller in amplitude than stations at the same latitude in the Northern Hemisphere as a consequence of the relatively weak seasonal SLP cycle.

A summary of the phase of the semiannual MSL cycle is shown in Fig.18. Cotidal lines divide the semiannual data into stations peaking between months 1.5 and 4.5 (i.e. approximately at the equinoxes) and those peaking between months 4.5 and 1.5 (i.e. approximately year start or middle). Cotidal lines drawn to a finer resolution than this are difficult to resolve on a world scale. In the Pacific the cotidal subdivisions agree well with those obtained by

Wyrtki and Leslie (1980). The world can be seen to be divided between stations in the tropics whose semiannual phase peaks around the equinoxes and those at higher latitudes which are in antiphase with the tropics. The major exception to this rule is for stations on the Central American Pacific coast which are also in approximate antiphase with the usual tropical semiannual cycle (Fig.12(d)).

A similar worldwide distribution for the semiannual MSL cycle was attempted by Lisitzin and Maksimov (Maksimov and Smirnov 1965, Listzin 1974) in an attempt to prove that the observed semiannual component of MSL is an approximation to the astronomical semiannual ocean tide (although with an amplification factor of six in the observed amplitudes compared to those expected from the equilibrium tide). The crux of their argument was that the peaking of the cycle around month 0.0 (and 6.0) at high latitudes and at month 3.0 (and 9.0) in the tropics is just as required for the astronomical semiannual tide (Doodson and Warburg 1941). This is a consequence, however, of the various factors which contribute to the semiannual cycle conspiring to produce a worldwide phase distribution with a behaviour not unlike that of the long period tide. The preceding sections have demonstrated that the semiannual MSL component in the tropics (e.g. in the Gulf of Mexico and the east coast of the USA, Truk Island etc.) can be explained by the semiannual character of winds, heating and ocean currents most of which have maximum effect at the equinoxes. A large half-yearly oscillation in the tropical troposphere is also present (Van Loon and Jenne 1970) which has nothing to do with astronomical factors. Conversely, in the high northern latitudes, the semiannual contribution from SLP peaks around month 0.0 (Figs.1(d),8(d),12(d),15(d)) and forms a large part of the observed MSL semiannual signal. The semiannual component of SLP and winds in the high southern latitudes has been discussed by Van Loon and Rogers (1984).

Although it is certain that there will be an astronomical contributions to the annual and semiannual MSL cycles close to their equilibrium values (Proudman 1960), with amplitudes proportional to $\frac{3}{2}\sin^2\theta - \frac{1}{2}$ (where θ is latitude), an important question remains as to whether the existing MSL data are adequate to allow the clear identification of such terms. If the astronomical tides have their equilibrium values (Pattullo et al 1955, Proudman 1960) then the amplitude of the annual tide is never larger than 3mm anywhere in the world. The amplitude of the equilibrium semiannual tide is smaller than 10mm except at higher latitudes than 60deg N or S where it peaks at month 5.7 and has a maximum value of 14mm at the poles. Any amplitude below 10mm would be very difficult to separate from the meteorological and other factors contributing to the semiannual cycle, althought Cartwright (1983) has shown that at Newlyn (50deg N) the SLP-corrected MSL semiannual cycle is at least comparable to the equilibrium prediction. There are, however, only 16 stations in Groups 1-3 situated north of 60deg N, 12 of which are in Norway. The three stations in Antarctica lie south of 60deg S. Table 8 reproduces the parameters of the semiannual MSL cycle from Tables 1-3 for these stations together with an estimate of the SLP contributions. If other factors (winds, steric levels etc.) are unimportant (which is unlikely) then the MSL cycle minus the SLP contribution might be accountable by the astronomical part of the semiannual cycle.

In Antartica the SLP term is not a small factor and can clearly account for most or all of the MSL cycle. In the Northern Hemisphere (but not Norway) encouraging results are obtained, the MSL-SLP signal having amplitude and phase approximately as expected for the equilibrium tide. However, the Norwegian data consistently have phase too early for the equilbrium tide, and other factors are obviously present in their MSL semiannual cycles. The conclusion, therefore, is that the astronomical contribution to the semiannual MSL cycle is not quantitatively verifiable with the existing world MSL dataset.

A worldwide summary of the amplitude of the MSL annual cycle is shown in Fig.19. The exact locations of the 'corange lines' in this figure are even more flexible than for the 'cotidal lines' attempted previously and it is likely that different people using the same data from Tables 1-3 could draw somewhat different looking maps. However, the main items of large amplitudes in S.E.Asia, northern Australia, the Gulf of California, the Arabian Sea and the high northern latitudes stand out immediately. In the Southern Hemisphere, the diminished role of SLP results in smaller amplitudes, while ocean islands tend to have smaller signals than do stations on continental coastlines (Wyrtki and Leslie 1980).

An attempt at a 'corange map' for the semiannual cycle is not presented here. With the exception of the Gulf of Mexico and the USA East Coast and the area of the Bay of Bengal, observed amplitudes are typically 20-50mm and subject to large uncertainties. Nevertheless, in regions where there are a large number of tide gauges, the previous sections have shown that good estimates of the semiannual amplitude can be made. With an increasing number of tide gauges being planned for installation around the world, better annual and semiannual worldwide summaries should one day be possible.

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Table 1. Station information and MSL seasonal cycle parameters for stations in Group 1. NY, NS and NF denote the number of years of available data, and the first and last years of data respectively. ASA and ASSA are the amplitudes (in mm) of the annual and semiannual cycles respectively, while PSA and PSSA give the number of months from the start of the year at which the cycles are a maximum. Δ is the standard error of the amplitudes ASA and ASSA (in mm) while σ describes the residual standard deviation in the data after the regression fit of Method 1.

Station	Lat.	Lon.	NY	NS	NF	ASA	PSA	ASSA	PSSA	Δ	σ
AMERICAN PACIFIC COAST											
SWEEPER COVE	51 51N	176 39W	26	1944	1974	60.6	11.82	16.3	0.15	8.6	76.3
YAKUTAT	59 33N	139 44W	36	1940	1978	123.6	11.15	18.0	4.14	7.2	76.9
SITKA	57 03N	135 20W	41	1938	1979	119.5	11.47	19.2	4.64	6.3	67.6
SKAGWAY	59 27N	135 19W	29	1945	1974	100.6	8.86	17.6	5.02	11.6	106.6
JUNEAU	58 18N	134 25W	41	1936	1979	85.6	10.27	21.6	5.00	7.2	80.2
KETCHIKAN	55 20N	131 38W	56	1919	1975	107.0	11.47	28.5	5.11	6.2	78.8
PRINCE RUPERT	54 19N	130 20W	38	1933	1977	107.7	11.69	28.2	5.20	6.8	71.9
ALERT BAY	50 35N	126 57W	28	1949	1977	106.9	12.00	18.1	0.04	7.3	67.9
POINT ATKINSON	49 20N	123 15W	39	1915	1977	50.9	11.44	35.3	0.22	6.1	65.2
VANCOUVER	49 17N	123 07W	47	1911	1977	57.6	11.52	31.9	0.24	5.4	65.9
VICTORIA	48 25N	123 22W	64	1910	1977	81.6	11.96	24.1	0.45	4.7	64.7
NEAH BAY	48 22N	124 37W	40	1935	1979	133.3	0.15	19.4	0.14	6.4	77.6
FRIDAY HARBOR (OCEAN LABS)	48 33N	123 00W	42	1934	1978	77.7	0.14	31.3	0.50	5.7	63.6
SEATTLE	47 36N	122 20W	81	1899	1979	75.8	0.33	26.7	0.34	4.0	62.6
ASTORIA (TONGUE POINT)	46 13N	123 46W	52	1926	1979	90.4	1.28	55.2	5.65	7.6	94.2
CRESCENT CITY	41 45N	124 12W	44	1933	1978	76.1	11.34	31.6	0.90	5.6	65.4
SAN FRANCISCO	37 48N	122 28W	126	1855	1980	30.5	9.73	25.6	1.15	3.0	58.5
ALMEDA (NAVAL AIR STATION)	37 46N	122 18W	40	1940	1979	30.7	10.08	26.3	1.13	5.0	55.2
AVILA	35 10N	120 44W	21	1946	1970	54.8	9.31	17.4	1.12	6.0	48.8

SANTA MONICA	34 01N	118 30W	38	1933	1979	62.8	8.75	17.4	1.23	3.9	43.9
LOS ANGELES	33 43N	118 16W	55	1924	1978	63.4	8.90	16.7	1.17	3.0	39.7
LA JOLLA	32 52N	117 15W	50	1925	1977	69.2	8.85	14.5	1.14	3.3	40.2
SAN DIEGO	32 43N	117 10W	72	1906	1979	66.4	8.85	14.6	1.16	3.1	48.2
LA UNION	13 20N	87 49W	20	1948	1968	56.5	7.58	15.7	0.04	6.8	52.8
PUNTARENAS	9 58N	84 50W	25	1942	1966	36.0	8.41	34.4	5.88	8.3	71.2
BALBOA	8 58N	79 34W	62	1908	1969	121.6	8.29	65.1	4.98	3.8	49.4
BUENAVENTURA	3 54N	77 06W	24	1941	1969	69.8	8.36	48.3	5.24	5.8	49.2
LA LIBERTAD	2 12S	80 55W	20	1950	1969	13.3	2.80	10.9	5.42	7.0	54.4
TALARA	4 37S	81 17W	28	1942	1969	47.2	3.07	9.6	1.06	4.9	45.6
MATARANI	17 00S	72 07W	25	1942	1969	43.0	2.50	6.8	5.80	4.3	36.4
ANTOFAGASTA	23 39S	70 25W	21	1946	1969	32.2	2.11	10.0	0.11	4.4	35.3
AMERICAN ATLANTIC COAST and NORTH CANADA											
PUERTO MADRYN	42 46S	65 02W	26	1945	1980	68.1	2.07	22.0	5.81	5.1	53.4
MAR DEL PLATA	38 03S	57 33W	23	1958	1980	75.4	2.16	14.5	5.36	5.5	56.0
BUENOS AIRES	34 36S	58 22W	22	1958	1980	89.8	1.06	29.0	3.13	10.0	81.2
PALERMO	34 34S	58 24W	21	1960	1980	94.3	0.90	34.3	3.04	10.3	81.7
MONTEVIDEO	34 55S	56 13W	25	1938	1970	60.1	2.62	13.7	3.98	7.0	81.1
IMBITUBA	28 14S	48 39W	20	1949	1968	55.3	3.74	11.0	4.58	7.3	57.1
RECIFE	8 03S	34 52W	20	1949	1968	42.5	4.26	6.8	4.24	4.9	38.1

BELEM	1 27S	48 30W	20	1949	1968	59.2	2.31	72.4	2.89	4.2	42.2
CARTAGENA	10 24N	75 33W	21	1949	1969	58.5	8.68	31.8	3.77	3.1	32.0
CRISTOBAL	9 21N	79 55W	61	1909	1969	30.0	9.84	9.1	4.35	2.4	32.0
PUERTO CORTES	15 50N	87 57W	21	1948	1968	68.4	8.54	28.6	3.32	2.9	32.3
ST.GEORGES,BERMUDA	32 22N	63 42W	37	1933	1979	70.3	8.93	10.9	3.63	7.0	87.5
GUANTANAMO BAY,CUBA	19 54N	75 09W	26	1938	1968	61.0	8.57	22.5	3.36	3.0	36.5
MAGUEYES IS.,PUERTO RICO	17 58N	67 03W	23	1955	1978	59.0	8.82	12.8	3.18	3.2	32.4
PORT ISABEL	26 04N	97 13W	29	1945	1973	64.3	9.17	74.5	3.55	6.6	68.3
FREEPORT	28 57N	95 19W	23	1955	1977	73.1	7.97	79.2	3.61	9.2	87.6
GALVESTON 2	29 19N	94 48W	69	1909	1978	69.6	7.72	74.8	3.62	5.4	83.9
EUGENE ISLAND	29 22N	91 23W	31	1940	1974	81.6	6.88	57.3	3.48	6.9	66.2
BAYOU RIGAUD	29 16N	89 58W	28	1947	1978	77.3	7.70	52.0	3.38	7.3	71.3
PENSACOLA	30 24N	87 13W	57	1924	1980	90.3	7.57	39.7	3.31	4.3	58.5
CEDAR KEYS 2	29 08N	83 02W	41	1939	1979	105.3	7.37	23.5	3.40	4.7	52.6
ST.PETERSBURG	27 46N	82 37W	28	1947	1974	89.0	7.69	19.5	3.46	4.7	45.9
KEY WEST (NAVAL BASE)	24 33N	81 48W	51	1926	1979	81.0	8.78	37.2	3.70	3.0	46.2
MIAMI BEACH	25 46N	80 08W	45	1932	1980	84.3	9.23	53.3	3.80	4.3	53.8
DAYTONA BEACH	29 14N	81 00W	23	1925	1969	100.6	9.34	66.7	3.68	9.2	80.8
MAYPORT	30 24N	81 26W	51	1929	1979	110.3	9.07	73.8	3.63	5.3	74.4
FERNANDINA	30 41N	81 28W	26	1898	1923	90.0	8.79	85.1	3.72	7.4	81.3
FORT PULASKI	32 02N	80 54W	45	1935	1980	94.8	8.44	66.0	3.64	4.5	72.0

CHARLESTON I	32 47N	79 56W	58	1922	1979	85.6	8.41	56.8	3.61	3.8	68.1
WILMINGTON	34 14N	77 57W	42	1936	1979	42.7	7.76	34.8	3.16	6.0	73.6
PORTSMOUTH	36 49N	76 18W	44	1936	1979	61.8	8.02	43.7	3.30	4.8	63.9
RICHMOND	37 34N	77 27W	25	1942	1966	81.3	2.78	94.7	2.90	17.1	183.7
HAMPTON ROADS	36 57N	76 20W	51	1928	1980	63.4	7.85	42.3	3.32	4.9	66.5
WASHINGTON D.C.	38 52N	77 01W	48	1932	1979	88.5	6.73	39.3	3.31	6.2	75.2
SOLOMON'S ISLAND	38 19N	76 27W	39	1938	1979	94.9	7.25	33.6	3.45	4.8	52.6
ANNAPOLIS	38 59N	76 29W	49	1929	1979	103.7	7.07	30.5	3.51	4.5	54.2
BALTIMORE	39 16N	76 35W	77	1903	1979	119.0	7.00	27.5	3.51	3.7	56.1
KIPTOPEKE BEACH	37 10N	75 59W	27	1952	1979	65.8	7.94	35.4	3.33	7.9	80.6
LEWES (BREAKWATER HARBOR)	38 47N	75 06W	33	1921	1979	62.0	7.65	32.8	3.38	5.9	62.0
CAPE COD CANAL ENTRANCE	41 46N	70 30W	20	1956	1975	13.6	8.74	11.7	3.87	4.8	47.0
PHILADELPHIA	39 57N	75 08W	55	1923	1979	83.9	6.45	40.1	3.49	5.8	78.0
WILLETS POINT	40 48N	73 47W	48	1932	1979	66.7	7.25	23.5	3.51	4.7	57.4
ATLANTIC CITY	39 21N	74 25W	60	1912	1975	67.3	7.57	24.2	3.32	4.2	58.5
SANDY HOOK	40 28N	74 01W	47	1933	1979	69.8	7.21	27.3	3.52	4.8	56.9
NEW YORK	40 42N	74 01W	50	1921	1975	73.0	7.13	25.2	3.56	4.5	55.1
MONTAUK	41 03N	71 58W	29	1948	1978	46.7	7.69	15.7	3.61	4.9	49.3
PORT JEFFERSON	40 57N	73 05W	20	1958	1978	55.3	7.47	24.2	3.55	6.4	51.4
NEW LONDON	41 22N	72 06W	38	1939	1976	49.7	7.32	19.5	3.71	4.1	44.5
PROVIDENCE	41 48N	71 24W	30	1939	1979	54.6	7.25	14.5	3.84	4.4	42.4

NEWPORT	41 30N	71 20W	46	1931	1979	51.5	7.69	11.4	3.77	3.4	43.1
WOODS HOLE	41 32N	70 40W	43	1933	1979	46.7	7.78	10.5	3.89	3.4	42.1
BOSTON	42 21N	71 03W	58	1922	1979	25.7	7.28	13.7	4.05	3.6	47.9
PORTSMOUTH	43 05N	70 45W	36	1927	1968	22.9	6.22	15.4	4.06	4.1	46.5
PORTLAND	43 40N	70 15W	66	1912	1978	27.9	6.75	12.1	4.39	3.5	50.0
BAR HARBOUR	44 23N	68 12W	29	1948	1979	10.2	7.34	8.0	4.62	4.4	41.9
EASTPORT	44 54N	66 59W	44	1930	1979	1.3	10.04	11.6	4.81	4.0	45.9
ST.JOHN N.B.	45 16N	66 04W	41	1906	1975	28.1	4.66	38.6	4.74	4.5	53.2
HALIFAX	44 40N	63 35W	61	1897	1979	44.9	11.92	6.4	5.14	2.8	44.4
CHARLOTTETOWN	46 14N	63 07W	39	1912	1974	45.3	11.15	14.4	5.92	3.5	45.3
POINTE-AU-PERE	48 31N	68 28W	34	1925	1977	22.5	6.03	28.5	5.11	5.4	62.8
HARRINGTON HBR.	50 30N	59 29W	33	1940	1977	44.4	10.32	14.5	5.73	4.6	46.8
CHURCHILL	58 46N	94 11W	29	1940	1977	91.0	9.35	30.4	5.20	9.1	90.1
EUROPE and AFRICA											
RUSSKAYA GAVAN	76 14N	62 39E	27	1953	1980	116.5	10.01	22.9	5.88	9.6	86.4
MURMANSK	68 58N	33 03E	28	1952	1979	89.4	9.97	15.5	5.90	9.0	82.3
TROMSO	69 39N	18 58E	24	1953	1977	115.6	10.70	18.8	5.96	9.1	82.5
HARSTAD	68 48N	16 33E	22	1953	1977	119.9	10.72	15.2	5.55	9.2	80.7
NARVIK	68 26N	17 25E	35	1929	1973	131.5	10.60	21.0	5.53	9.3	100.3
KABELVAG	68 13N	14 29E	28	1948	1977	134.0	10.94	14.5	4.89	9.7	101.3
TRONDHEIM	63 26N	10 26E	28	1949	1977	96.8	10.54	26.1	5.14	9.5	91.0

HEIMSJO	63 26N	9 07E	33	1935	1973	120.9	10.74	11.0	5.05	8.2	88.6
KRISTIANSUND N.	63 07N	7 44E	24	1953	1976	131.0	10.63	15.0	4.93	9.8	88.4
ALESUND	62 28N	6 09E	25	1951	1977	132.2	10.55	14.1	4.91	9.8	88.7
KJOLSDAL	61 55N	5 38E	23	1935	1973	113.9	10.11	5.9	4.77	10.8	90.2
MALOY	61 56N	05 07E	24	1946	1977	124.5	10.35	15.9	4.46	9.8	84.3
BERGEN	60 24N	5 18E	45	1883	1973	104.8	10.02	16.8	5.11	6.1	70.8
STAVANGER	58 58N	5 44E	33	1928	1973	99.3	10.07	13.4	5.07	7.4	73.2
TREGDE	58 00N	7 34E	34	1935	1972	80.3	9.80	8.7	5.40	6.2	62.8
OSLO	59 54N	10 45E	46	1886	1973	118.3	8.81	19.9	5.93	7.8	112.2
OOSTENDE	51 14N	2 55E	32	1937	1977	63.8	9.83	11.2	5.07	6.5	63.5
LERWICK	60 09N	1 08W	20	1957	1978	90.2	10.35	14.3	5.81	7.7	60.7
ABERDEEN 1	57 09N	2 05W	36	1932	1972	81.9	10.43	6.5	4.90	6.0	64.0
ABERDEEN 2	57 09N	2 05W	103	1862	1965	88.9	10.57	15.9	5.67	3.5	64.6
SOUTHEND	51 31N	0 44E	42	1929	1979	48.4	9.49	9.6	4.05	4.6	53.5
NEWLYN	50 06N	5 33W	65	1916	1980	53.2	10.53	10.4	4.40	4.8	69.4
DOUGLAS	54 09N	4 28W	32	1938	1977	75.7	10.46	13.4	5.43	8.3	84.0
NORTH SHIELDS	55 00N	1 27W	69	1897	1973	69.2	10.23	11.0	5.44	4.4	64.3
SHEERNESS	51 27N	0 45E	57	1834	1981	45.9	9.46	15.9	4.29	4.5	61.6
LOWESTOFT	52 28N	1 19E	21	1956	1980	73.4	9.55	16.6	4.56	6.9	56.5
BREST	48 23N	4 30W	151	1807	1981	49.1	10.59	18.9	4.30	3.5	78.2
SANTANDER 1	43 28N	3 48W	20	1944	1966	45.9	10.59	17.9	3.95	9.4	76.2

LA CORUNA 1	43 22N	8 24W	22	1944	1967	41.5	11.07	17.8	3.86	8.8	84.2
LA CORUNA 2	43 22N	8 24W	23	1955	1978	52.5	11.51	5.6	4.29	5.8	67.6
VIGO	42 19N	8 44W	20	1944	1963	37.8	11.66	22.7	3.98	7.6	77.5
CASCAIS	38 41N	9 25W	92	1882	1979	24.8	9.66	21.0	3.82	3.4	57.3
LAGOS	37 06N	8 40W	56	1909	1978	41.2	9.10	16.7	3.83	4.9	71.1
REYKJAVIK	64 09N	21 56W	23	1957	1981	78.0	10.14	11.1	0.25	9.4	78.6
BARENTSBURG	78 04N	15 14E	30	1949	1979	92.9	9.85	21.0	0.39	7.2	68.9
SANTA CRUZ DE TENERIFE 1	28 29N	16 14W	41	1927	1974	61.5	7.88	14.2	2.57	3.0	36.6
TAKORADI	4 53N	1 45W	52	1930	1982	61.4	0.74	51.6	3.84	7.7	96.8
SIMONS BAY	34 11S	18 26E	21	1958	1980	28.1	0.64	2.8	0.39	3.8	30.5
BALTIC (incl. DENMARK)											
GEDSER	54 34N	11 58E	72	1898	1969	55.6	8.44	23.4	1.14	4.3	86.2
KOBENHAVN	55 41N	12 36E	80	1889	1969	79.7	8.84	25.1	0.84	4.3	80.9
HORNBAEK	56 06N	12 28E	69	1898	1969	91.4	8.63	25.7	0.58	4.9	93.8
KORSOR	55 20N	11 08E	73	1897	1969	63.8	8.93	15.9	0.90	3.5	61.1
SLIPSHAVN	55 17N	10 50E	69	1896	1968	62.4	9.00	16.7	0.95	3.6	59.2
FREDERICIA	55 34N	9 46E	78	1890	1969	61.1	9.35	9.2	0.73	2.9	47.9
AARHUS	56 09N	10 13E	78	1889	1968	74.2	9.40	15.2	0.55	3.5	56.6
FREDERIKSHAVN	57 26N	10 34E	72	1894	1969	88.1	9.33	23.7	0.32	5.0	78.9
HIRTSHALS	57 36N	9 57E	71	1892	1969	94.6	9.07	26.6	0.38	6.4	105.1
ESBJERG	55 28N	8 27E	80	1890	1969	115.4	9.84	21.8	0.21	9.4	146.6

STROMSTAD	58 57N	11 11E	59	1900	1965	92.1	9.10	33.0	0.06	6.4	96.1
SMOGEN	58 22N	11 13E	71	1911	1981	97.0	9.23	19.0	5.93	5.3	84.6
GOTEBORG-KLIPPAN	57 43N	11 57E	81	1887	1968	94.9	9.16	25.9	0.50	5.7	98.3
VARBERG	57 06N	12 13E	93	1887	1980	96.9	9.11	20.1	0.38	4.8	90.2
KLAGSHAMN	55 31N	12 54E	51	1930	1981	75.7	9.16	23.3	0.42	7.0	95.6
YSTAD	55 25N	13 49E	95	1887	1981	73.0	9.29	27.5	0.80	5.6	102.2
KUNGHOLMSFORT	56 06N	15 35E	94	1887	1981	81.2	9.30	33.4	0.77	6.5	116.0
OLANDS NORRA UDDE	57 22N	17 06E	59	1923	1981	108.6	9.44	33.0	0.34	9.8	136.3
LANDSORT	58 45N	17 52E	95	1887	1981	98.2	9.46	42.5	0.67	7.5	132.4
NEDRE SODERTALJE	59 12N	17 37E	97	1869	1965	91.6	9.38	47.8	0.78	7.3	130.7
STOCKHOLM	59 19N	18 05E	93	1889	1981	94.2	9.54	42.0	0.64	7.8	134.9
BJORN	60 38N	17 58E	85	1892	1976	103.2	9.70	44.2	0.61	8.7	141.3
NEDRE GAVLE	60 40N	17 10E	70	1896	1965	96.1	9.64	51.4	0.66	9.2	136.1
DRAGHALLAN	62 20N	17 28E	77	1898	1974	98.3	9.65	46.7	0.53	9.3	143.6
RATAN	64 00N	20 55E	88	1892	1981	111.7	9.94	42.6	0.48	9.4	153.5
FURUOGRUND	64 55N	21 14E	66	1916	1981	120.9	9.96	41.4	0.11	11.2	157.5
KEMI	65 44N	24 33E	53	1920	1976	126.0	10.01	42.7	0.15	13.1	165.1
OULU/ULEABORG	65 02N	25 26E	77	1889	1977	104.0	10.15	46.9	0.61	10.6	161.3
RAAHE/BRAHESTAD	64 42N	24 30E	43	1923	1972	126.3	9.87	35.6	0.07	13.9	158.1
YKSPIHLAJA	63 50N	23 02E	36	1889	1924	92.1	9.88	60.5	0.96	13.9	145.1
PIETARSAARI/JAKOBSTAD	63 42N	22 42E	63	1915	1978	118.8	9.83	39.1	0.27	11.3	155.9

VAASA/VASA	63 06N	21 34E	84	1884	1977	115.6	9.82	48.1	0.49	9.1	145.9
RONNSKAR	63 04N	20 48E	61	1867	1936	113.3	9.90	54.1	0.78	10.4	141.5
KASKINEN/KASKO	62 23N	21 13E	47	1927	1977	108.8	9.85	41.6	0.20	12.7	151.0
MANTYLUOTO	61 36N	21 29E	66	1911	1978	107.9	9.72	36.8	0.32	10.6	150.5
RAUMA/RAUMO	61 08N	21 29E	42	1935	1978	106.7	9.72	33.4	0.21	13.6	154.4
LYOKKI	60 51N	21 11E	78	1858	1936	105.6	9.69	53.6	0.82	9.2	142.0
LYPYRTTI	60 36N	21 14E	77	1858	1936	104.7	9.66	51.3	0.78	9.0	139.3
TURKU/ABO	60 25N	22 06E	54	1922	1978	112.2	9.51	36.6	0.24	11.6	152.8
LEMSTROM	60 06N	20 01E	48	1889	1936	100.3	9.67	55.9	0.99	10.9	132.7
DEGERBY	60 02N	20 23E	47	1924	1977	96.9	9.60	36.6	0.48	11.8	143.7
UTO	59 47N	21 22E	69	1866	1936	104.7	9.53	51.5	0.77	9.4	138.9
JUNGFRUSUND	59 57N	22 22E	77	1858	1934	97.2	9.46	52.6	0.84	9.0	142.6
RUSSARO	59 46N	22 57E	67	1866	1936	102.0	9.54	49.6	0.73	9.9	144.8
HANKO/HANGO	59 49N	22 58E	61	1897	1978	107.9	9.64	36.9	0.46	10.7	147.7
SKURU	60 06N	23 33E	37	1900	1936	95.4	9.30	45.6	0.76	13.1	147.7
HELSINKI	60 09N	24 58E	99	1879	1977	106.9	9.56	44.7	0.59	8.7	154.0
SODERSKAR	60 07N	25 25E	71	1866	1936	105.6	9.39	50.9	0.76	9.7	149.2
HAMINA	60 34N	27 11E	47	1929	1978	116.3	9.62	33.5	0.32	14.0	170.0
VYBORG	60 42N	28 44E	50	1889	1938	131.3	9.44	46.5	0.84	12.6	161.8
DAUGAVGRIVA	57 03N	24 02E	60	1872	1938	87.6	8.57	39.2	0.92	9.3	170.4
LIEPAJA	56 32N	20 59E	63	1865	1936	103.4	9.24	41.9	0.65	9.7	144.3

KALININGRAD	54 57N	20 13E	45	1926	1980	107.4	9.09	28.1	0.47	10.8	140.7
HEL	54 36N	18 48E	25	1901	1966	66.0	8.99	62.8	1.16	12.9	129.7
MEDITERRANEAN and BLACK SEA											
MARSEILLE	43 18N	05 21E	74	1886	1963	39.9	10.51	29.4	4.48	3.9	60.1
CAGLIARI	39 12N	9 10E	26	1897	1934	61.9	8.54	15.8	3.97	3.7	45.0
PORTO MAURIZIO	43 52N	8 01E	23	1897	1921	33.2	9.28	24.1	4.46	5.9	52.5
GENOVA	44 24N	8 54E	61	1884	1968	35.7	9.25	23.6	4.48	3.9	57.1
CIVITAVECCHIA	42 03N	11 49E	21	1897	1920	34.0	10.71	20.9	4.45	6.5	55.3
VENEZIA (S.STEFANO)	45 25N	12 20E	21	1896	1919	38.1	9.56	39.8	4.45	10.0	81.5
TRIESTE	45 39N	13 45E	71	1905	1981	37.6	9.47	33.1	4.66	5.0	76.2
BAKAR	45 18N	14 32E	30	1930	1974	46.9	10.93	27.1	4.81	7.5	80.9
SPLIT RT MARJANA	43 30N	16 23E	20	1953	1974	41.7	11.37	24.1	5.05	6.9	70.9
PORT TUAPSE	44 06N	39 04E	63	1917	1980	77.8	5.03	39.9	0.46	5.3	85.0
AUSTRALIA											
NEWCASTLE 1	32 55S	151 48E	25	1928	1960	43.7	4.17	18.7	4.93	7.6	66.1
NEWCASTLE 3	32 55S	151 48E	56	1926	1981	45.6	4.00	21.8	5.00	4.9	63.9
SYDNEY,FORT DENISON	33 51S	151 14E	85	1897	1981	38.0	3.95	21.3	4.92	3.5	56.5
CAMP COVE	33 50S	151 17E	30	1949	1981	45.2	4.17	31.6	4.92	5.2	49.4
PORT ADELAIDE (INNER HBR)	34 51S	138 30E	30	1882	1976	66.2	6.05	27.1	5.55	7.6	82.6
PORT ADELAIDE (OUTER HBR)	34 47S	138 28E	23	1944	1970	66.6	5.92	35.2	5.26	7.7	75.8

PACIFIC

MANILA	14 35N	120 58E	56	1902	1981	128.1	7.55	14.9	2.71	6.3	84.9
LEGASPI	13 09N	123 45E	29	1949	1981	59.0	6.95	8.7	3.67	5.9	54.9
CEBU	10 18N	123 54E	24	1938	1981	74.8	7.39	11.8	4.15	6.7	58.3
DAVAO	07 05N	125 38E	23	1949	1981	64.2	7.25	21.1	3.41	7.7	64.4
JOLO	06 04N	121 00E	20	1948	1980	29.9	7.82	18.4	3.82	6.4	54.5
APRA HARBOR,GUAM	13 26N	144 39E	28	1948	1977	60.7	5.76	14.1	2.08	6.5	74.7
TRUK,MOEN ISLAND	07 27N	151 51E	20	1953	1974	29.8	4.70	31.2	3.24	9.2	76.0
ENIWETOK	11 22N	162 21E	20	1952	1971	41.7	6.56	13.3	2.72	7.1	56.5
KWAJALEIN	08 44N	167 44E	31	1947	1977	25.3	5.59	25.1	3.08	4.2	54.8
WAKE ISLAND	19 17N	166 37E	24	1951	1977	32.5	8.94	15.0	2.24	7.0	70.0
PAGO PAGO	14 17S	170 41W	27	1949	1977	16.5	6.11	5.2	3.55	5.3	53.1
CANTON ISLAND	02 49S	171 43W	20	1950	1974	39.0	10.70	2.8	1.27	4.9	41.0
MIDWAY ISLAND	28 13N	177 22W	26	1947	1972	50.1	10.32	17.6	1.43	7.2	64.3
JOHNSTON ISLAND	16 45N	169 31W	25	1950	1977	69.1	9.90	6.4	2.38	8.1	69.9
NAWILIWILI BAY,KAUAI ISLAND	21 58N	159 21W	25	1955	1979	51.4	9.57	14.9	2.46	8.4	74.4
HONOLULU	21 19N	157 52W	76	1905	1980	40.6	9.27	9.9	2.34	3.0	49.6
KAHULUI HARBOR,MAUI ISLAND	20 54N	156 28W	26	1951	1978	44.8	9.28	14.5	2.19	4.9	46.1
HILO,HAWAII ISLAND	19 44N	155 04W	32	1947	1978	47.5	9.23	14.5	2.34	5.0	53.3

ASIA

ADEN	12 47N	44 59E	55	1880	1969	111.1	2.50	35.3	4.85	2.3	41.6
BHAUNAGAR	21 45N	72 14E	25	1937	1964	233.5	7.96	20.5	1.55	18.7	184.5
BOMBAY (APOLLO BANDAR)	18 55N	72 50E	86	1878	1964	22.6	2.09	34.3	5.99	2.8	54.1
COCHIN (WILLINGDON IS.)	09 58N	76 16E	30	1939	1977	77.1	0.60	25.1	5.72	5.6	54.3
MADRAS	13 06N	80 18E	22	1916	1978	99.2	9.90	91.5	4.71	7.6	61.6
VISHAKHAPATNAM	17 41N	83 17E	34	1937	1976	171.7	8.97	89.9	4.65	6.2	73.1
SAUGOR	21 39N	88 03E	25	1937	1964	259.1	7.73	44.5	4.74	9.4	87.9
CALCUTTA (GARDEN REACH)	22 33N	88 18E	31	1932	1964	616.6	7.80	177.1	2.48	14.5	152.9
KIDDERPORE	22 32N	88 20E	21	1882	1931	774.2	7.82	240.1	2.28	21.0	183.7
MACAU	22 12N	113 33E	31	1937	1967	99.1	9.56	55.6	3.71	7.6	74.9
NORTH POINT	22 18N	114 12E	29	1950	1981	112.8	10.11	55.6	3.66	8.2	76.9
MOKPO	34 47N	126 23E	23	1960	1982	171.6	7.40	27.5	1.97	5.6	47.4
YUZHNO KURILSK	44 01N	145 52E	27	1952	1980	43.4	10.58	38.9	0.87	6.2	58.8
NAGAEVA BAY	59 44N	150 42E	22	1958	1979	30.3	9.57	30.1	0.04	7.3	61.0
PETROPAVLOVSK	53 00N	158 38E	23	1958	1980	86.5	0.57	44.0	0.74	8.4	71.7
XIAMEN	24 27N	118 04E	27	1954	1980	135.9	10.07	51.4	3.61	11.7	105.6
YANTAI	37 32N	121 23E	27	1954	1980	227.1	7.09	22.3	1.70	13.3	120.0
QINHUANGDAO	39 54N	119 36E	29	1950	1980	291.8	6.79	22.9	2.06	6.3	58.9
KUSHIRO	42 58N	144 23E	21	1958	1979	32.4	9.68	37.1	0.98	4.9	39.5
OSHORO 1	43 13N	140 52E	31	1930	1962	94.7	7.82	20.9	0.50	3.9	41.7

ONAHAMA	36 56N	140 55E	20	1958	1979	105.8	8.86	21.3	0.96	4.1	38.3
MERA	34 55N	139 50E	20	1958	1979	79.0	8.77	10.5	0.72	4.9	47.5
YOKOSUKA	35 17N	139 39E	20	1957	1980	92.2	8.39	11.8	0.75	4.8	49.5
ABURATSUBO	35 09N	139 37E	47	1930	1980	86.0	8.54	10.4	0.54	6.1	100.1
SHIMIZU-MINATO	35 01N	138 30E	22	1958	1979	106.9	8.34	2.7	5.97	6.0	64.1
NAGOYA	35 05N	136 53E	22	1958	1979	157.4	7.73	6.2	3.89	8.5	74.6
KOBE	34 41N	135 11E	21	1958	1979	167.8	7.74	13.9	1.67	7.5	63.8
TOSA SHIMIZU	32 47N	132 58E	21	1958	1979	135.0	7.78	17.4	2.52	6.7	57.8
TAKAMATSU	34 21N	134 03E	21	1958	1978	173.0	7.69	12.3	2.21	6.8	57.4
MOZI	33 57N	130 58E	22	1959	1980	188.5	7.67	10.5	1.67	5.4	46.6
HOSOJIMA	32 26N	131 40E	50	1930	1979	138.5	7.75	12.8	2.93	4.8	64.2
IZUHARA	34 12N	129 18E	23	1952	1980	175.9	7.86	13.2	1.70	7.8	72.3
SHIMONOSEKI 1	33 58N	130 57E	20	1958	1979	191.8	7.63	7.6	1.09	7.5	61.7
TONOURA	34 54N	132 04E	20	1958	1979	190.9	7.80	23.8	0.99	5.5	46.3
MAIZURU 1	35 29N	135 24E	29	1951	1980	176.0	8.11	27.7	0.68	4.0	44.2
WAJIMA	37 24N	136 54E	50	1930	1980	150.8	8.27	35.4	0.49	3.2	50.4
KASHIWAZAKI	37 21N	138 31E	24	1956	1980	144.7	8.56	41.6	0.59	4.4	51.4
OMINATO	41 15N	141 09E	25	1953	1980	107.7	8.48	26.9	0.68	4.5	54.4
ASAMUSHI	40 54N	140 52E	26	1955	1980	106.0	8.45	29.8	0.71	3.7	44.6
KAINAN	34 09N	135 12E	25	1954	1980	147.7	7.77	4.2	0.96	6.5	61.4

Table 2. Station information and MSL seasonal cycle parameters for stations in Group 2. For notation, see Table 1.

Station	Lat.	Lon.	NY	NS	NF	ASA	PSA	ASSA	PSSA	Δ
BACKEVIK	58 22N	11 15E	34	1895	1928	80.2	9.26	32.8	0.46	2.3
MEM	58 29N	16 25E	38	1887	1924	59.1	9.55	54.1	1.08	8.4
REPOSAARI	61 37N	21 27E	38	1889	1926	90.2	10.01	61.1	1.00	4.6
STROMMA	60 11N	22 53E	37	1899	1936	104.6	9.72	52.8	0.84	5.0
RIGA OLD IRON BRIDGE	56 57N	24 07E	55	1873	1936	48.9	4.50	65.7	3.59	47.8
KOLKASRAGS	57 48N	22 38E	34	1884	1936	113.3	9.29	56.9	0.77	6.2
VENTSPILS	57 24N	21 33E	54	1873	1936	106.2	9.41	45.7	0.80	3.5
MEMEL	55 43N	21 07E	21	1898	1918	68.1	10.08	58.8	1.09	15.2
PILLAU	54 38N	19 54E	45	1898	1943	86.4	8.76	47.8	1.03	6.1
GDANSK/NOWY PORT	54 24N	18 50E	62	1886	1970	85.0	8.79	40.0	1.08	5.9
STOLPMUNDE	54 35N	16 51E	33	1911	1943	88.3	8.85	34.8	0.98	6.4
ARKONA	54 41N	13 26E	48	1882	1934	69.0	8.94	30.3	1.07	5.0
WARNEMUNDE	54 11N	12 05E	90	1882	1980	56.1	8.17	24.4	1.03	4.1
WISMAR	53 54N	11 28E	89	1882	1980	51.2	7.78	22.2	1.04	4.2
TRAVEMUNDE	53 58N	10 53E	87	1855	1943	47.7	7.89	16.6	1.27	2.4
MARIENLEUCHTE	54 30N	11 15E	58	1882	1943	53.3	8.09	22.6	1.29	4.3
KIEL	54 20N	10 08E	23	1956	1978	13.6	10.90	12.6	3.43	6.6
CUXHAVEN	53 52N	08 43E	21	1938	1959	91.5	9.17	14.6	5.44	12.4
BREMERHAVEN	53 33N	08 34E	46	1898	1943	76.1	9.03	21.1	0.38	6.6
DELFZIJL	53 20N	06 56E	117	1865	1981	80.0	9.47	14.8	5.76	4.9

TERSCHELLING	53 22N	05 13E	61	1921	1981	100.3	9.74	18.0	5.15	4.6
HARLINGEN	53 10N	05 25E	117	1865	1981	91.8	9.65	13.5	5.90	4.5
DEN HELDER	52 58N	04 45E	116	1865	1981	90.9	9.82	12.9	5.73	3.6
IJMUIDEN	52 28N	04 35E	111	1871	1981	83.4	9.53	13.7	5.53	4.0
HOEK VAN HOLLAND	51 59N	04 07E	116	1864	1981	112.2	9.66	29.8	5.09	9.3
MAASLUIS	51 55N	04 15E	89	1848	1936	49.2	9.75	10.1	0.33	4.4
HELLEVOETSLUIS	51 49N	04 08E	108	1861	1968	60.6	9.29	8.5	5.67	4.1
BROWERSHAVEN	51 44N	03 54E	97	1872	1968	65.4	9.20	8.1	5.20	3.5
ZIERIKZEE	51 38N	03 55E	110	1872	1981	62.4	9.24	10.2	5.02	4.1
VLISSINGEN	51 27N	03 36E	120	1862	1981	60.3	9.24	7.7	4.89	3.2
DUNBAR	56 00N	02 31W	38	1914	1973	71.4	10.17	10.4	5.69	3.2
BLYTH	55 07N	01 29W	21	1955	1975	77.3	9.81	14.5	4.84	4.0
FELIXSTOWE	51 56N	01 19E	25	1918	1950	52.7	9.31	8.2	3.75	3.9
TILBURY	51 28N	00 22E	37	1930	1976	39.1	10.07	9.1	4.05	5.1
TOWER PIER	51 30N	00 05E	36	1929	1976	34.9	11.26	10.5	4.31	2.4
DOVER	51 07N	01 19E	21	1955	1975	69.0	9.71	13.2	4.92	3.7
PORTSMOUTH	50 48N	01 07W	21	1930	1981	104.2	9.30	28.5	4.56	15.1
AVONMOUTH	51 30N	02 43W	30	1925	1958	71.3	9.82	8.5	0.13	6.8
MILFORD HAVEN	51 42N	05 01W	24	1886	1979	61.3	10.53	15.3	5.34	5.6
HOLYHEAD	53 19N	04 37W	34	1839	1971	70.2	10.43	11.0	4.76	5.5
LIVERPOOL PRINCES PIER	53 25N	03 00W	33	1918	1975	84.8	10.19	22.0	5.55	5.6

LIVERPOOL GEORGES PIER	53 24N	03 00W	39	1858	1911	65.8	10.04	6.4	5.41	4.5
DUBLIN	53 21N	06 13W	44	1938	1982	55.5	10.27	10.5	4.98	4.0
MONACO	43 44N	07 25E	20	1902	1921	42.4	11.43	16.1	4.35	6.4
MESSINA	38 12N	15 34E	24	1897	1922	35.7	10.40	22.1	4.49	4.8
PORTO CORSINI	44 30N	12 17E	54	1897	1972	43.9	10.66	31.3	4.62	5.7
SPLIT HARBOUR	43 30N	16 26E	26	1931	1974	52.9	11.45	26.7	4.89	4.7
IZMIR	38 24N	27 10E	34	1937	1971	35.8	7.95	21.4	0.35	5.0
ANTALYA	36 53N	30 42E	34	1936	1972	66.6	8.31	42.2	0.71	5.8
PORT SAID	31 15N	32 18E	23	1923	1946	88.2	8.74	26.8	0.75	4.9
PORT THEWFIK	29 57N	32 34E	23	1923	1946	127.4	1.10	56.2	5.01	11.4
PONTA DELGADA	37 44N	25 41W	22	1924	1957	36.5	9.43	4.5	1.61	1.5
HORTA	38 32N	28 38W	44	1906	1976	31.6	8.68	3.5	0.21	0.8
KARACHI	24 48N	66 58E	22	1916	1965	43.3	5.20	33.5	5.33	5.4
RANGOON	16 46N	96 10E	24	1916	1962	427.1	7.53	37.8	2.41	8.4
KO TAPHAO NOI	07 50N	98 26E	35	1940	1981	100.5	7.48	56.8	4.78	5.4
PHRACHUAP KIRIKHAN	11 48N	99 49E	39	1940	1981	212.9	0.17	38.5	4.26	10.0
BANGKOK BAR	13 27N	100 36E	49	1926	1980	163.1	0.27	27.6	3.47	7.3
FORT PHRACHULA CHOMKLAO	13 33N	100 35E	37	1940	1981	145.9	0.26	29.3	3.52	7.7
KO SICHANG	13 09N	100 49E	39	1940	1981	172.3	0.27	21.6	3.54	7.9
TAKAO	23 37N	120 16E	39	1904	1943	121.0	7.35	21.7	2.69	4.2
HONTO	46 41N	141 51E	22	1923	1944	28.4	9.27	29.8	0.09	5.0

HANASAKI	43 17N	145 35E	53	1900	1976	35.7	10.49	31.5	0.82	5.3
OTARU	43 13N	141 03E	28	1906	1933	99.6	7.94	17.9	0.40	4.4
FUKABORI	32 41N	129 49E	26	1900	1965	168.2	7.60	27.7	2.35	4.0
HAMADA	34 55N	132 04E	25	1900	1924	182.3	7.80	18.6	0.85	4.3
IWASAKI	40 35N	139 55E	33	1900	1966	125.9	8.22	28.7	0.34	6.1
WILLIAMSTOWN	37 52S	144 55E	47	1895	1976	29.8	5.83	29.0	5.10	2.9
TOFINO	49 09N	125 55W	37	1935	1977	125.0	0.04	22.3	0.36	4.5
ENSENADA	31 51N	116 38W	21	1957	1982	75.9	8.89	12.1	1.27	2.9
MANZANILLO	19 03N	104 20W	22	1957	1982	102.5	8.31	33.2	0.61	3.9
ACAPULCO	16 50N	99 55W	27	1952	1982	73.3	8.03	28.4	0.54	3.9
VALPARAISO	33 02S	71 38W	28	1942	1970	33.0	2.75	20.4	0.03	1.4
COMODORO RIVADAVIA	45 52S	67 29W	24	1912	1980	35.4	1.61	14.2	5.76	8.0
QUEQUEN I	38 35S	58 42W	36	1911	1966	66.2	2.33	22.6	5.93	4.2
COLONIA	34 28S	57 51W	25	1938	1970	69.3	1.41	24.1	3.01	7.3
LA GUAIRA	10 28N	66 56W	23	1953	1975	73.4	9.07	47.4	3.83	5.1
HUMBLE OIL PLATFORM A	29 10N	89 55W	20	1949	1969	77.0	7.86	44.3	3.36	8.9
FORT HAMILTON	40 37N	74 02W	28	1893	1920	88.7	7.23	28.7	3.98	5.5

Table 3. Station information and MSL seasonal cycle parameters for stations in Group 3. For notation, see Table 1.

Station	Lat.	Lon.	NY	NS	NF	ASA	PSA	ASSA	PSSA	Δ
STORNOWAY	58 12N	06 23W	16	1957	1978	89.5	10.76	2.5	5.74	8.1
MALIN HEAD	55 22N	07 20W	19	1959	1979	76.3	10.54	7.7	5.66	6.2
ANGRA DO HEROISMO	38 39N	27 14W	18	1933	1979	37.6	9.56	5.9	4.65	3.3
PORTO GRANDE (ST. VINCENT)	16 52N	24 59W	4	1947	1950	22.4	8.32	15.0	4.19	3.2
DAKAR	14 40N	17 25W	8	1958	1965	85.3	1.61	6.8	4.18	5.7
FORCADOS	05 21N	05 21E	4	1969	1972	35.6	10.01	51.0	2.98	7.1
POINTE NOIRE	04 47S	11 50E	4	1959	1979	82.0	0.48	56.9	3.11	5.6
WALVIS BAY	22 57S	14 30E	8	1959	1982	48.4	0.92	17.6	2.26	3.1
LUDERITZ	26 38S	15 09E	15	1959	1982	46.7	0.66	10.0	3.05	2.3
PORT NOLLOTH	29 15S	16 52E	15	1959	1982	28.0	0.96	6.0	2.19	3.3
GRANGER BAY	33 54S	18 25E	10	1968	1980	23.0	1.34	2.6	2.03	3.6
MOSSEL BAY	34 11S	22 09E	13	1959	1982	23.7	1.19	14.3	0.19	8.2
DURBAN	29 53S	31 00E	6	1971	1982	24.9	1.18	6.1	2.18	8.4
LOURENCO MARQUES	25 59S	32 34E	8	1961	1974	76.9	1.39	7.3	1.69	6.3
NOSY-BE	13 24S	48 17E	7	1959	1972	53.1	0.85	2.7	3.46	3.2
PORT VICTORIA	04 37S	55 27E	3	1964	1979	53.9	2.29	65.2	2.15	6.5
PORT LOUIS	20 09S	57 29E	16	1942	1965	77.7	1.24	4.0	1.19	3.2
DIEGO GARCIA	07 21S	72 28E	3	1960	1962	46.2	10.49	3.8	4.26	8.2
EILAT	29 33N	34 57E	6	1962	1967	118.7	1.06	44.6	4.54	11.6
MOULMEIN	16 29N	97 37E	10	1954	1963	718.1	7.46	180.2	1.70	14.1

PORT BLAIR	11 41N	92 46E	9	1916	1956	56.6	8.11	34.3	5.33	3.0
SEMBAWANG	01 28N	103 50E	8	1954	1975	149.9	0.01	26.1	5.05	5.4
SEMBILANGAN	07 06S	112 42E	7	1925	1931	46.6	10.47	37.7	1.68	5.1
WEIPA	12 41S	141 53E	5	1966	1972	322.7	0.92	72.5	1.85	13.1
CAIRNS	16 56S	145 47E	17	1958	1975	85.7	2.61	24.5	2.90	3.5
ALBANY	35 02S	117 53E	13	1958	1975	94.5	5.25	34.5	5.47	3.0
FREMANTLE	32 03S	115 443	18	1937	1977	100.1	5.02	31.8	5.45	4.6
PORT HEDLAND	20 19S	118 34E	16	1913	1973	107.4	2.26	24.2	3.90	2.5
AUCKLAND	36 51S	174 49E	8	1918	1961	38.0	3.68	9.6	0.45	5.3
PORT LYTTELTON	43 36S	172 43E	7	1923	1963	53.2	2.74	3.6	1.33	5.8
MASSACRE BAY	52 50N	173 11W	17	1944	1966	57.4	11.31	19.4	0.50	6.5
LA PAZ	24 10N	110 21W	12	1954	1966	128.7	8.48	14.8	2.45	3.2
GUAYMAS	27 55N	110 54W	9	1952	1965	185.3	7.44	33.5	1.49	9.0
ARICA	18 28S	70 20W	14	1952	1969	40.2	1.93	3.5	5.61	3.9
CALDERA	27 04S	70 50W	17	1952	1970	32.1	2.09	14.1	5.98	3.0
TALCAHUANO	36 41S	73 06W	16	1950	1970	39.8	4.76	32.5	0.20	2.4
PUERTO MONTT	41 29S	72 58W	12	1942	1970	23.2	4.49	40.4	0.17	2.3
USHUAIA 1	54 49S	68 13W	7	1958	1967	29.0	2.08	17.7	5.61	9.8
USHUAIA 2	54 49S	68 13W	7	1971	1980	31.6	2.72	12.5	0.16	11.3
LA PLATA	34 55S	57 56W	19	1916	1934	72.4	1.51	4.6	2.66	2.9
STANLEY	51 42S	57 52W	3	1965	1968	24.6	1.64	33.1	5.44	9.8

KING EDWARD POINT	54 17S	36 30W	2	1958	1959	38.9	1.96	28.7	5.90	11.6
PUNTA DEL ESTE	34 58S	54 57W	14	1938	1970	71.2	2.89	22.9	4.42	12.1
RIO DE JANEIRO	22 56S	43 08W	13	1950	1967	41.7	3.43	9.8	3.83	3.8
CANAVIEIRAS	15 40S	38 58W	12	1952	1963	38.5	3.56	18.3	4.18	3.2
SALVADOR	12 58S	38 31W	19	1949	1968	41.7	3.86	13.9	4.23	3.2
FORTALEZA	03 43S	38 29W	16	1949	1968	17.0	9.79	8.6	3.77	2.2
SALINOPOLIS	00 39S	47 23W	4	1952	1955	16.7	2.69	58.9	2.70	6.8
CARUPANO	10 40N	63 15W	9	1967	1975	65.4	9.35	37.4	3.82	6.2
BAHIA ESPERANZA	63 18S	56 55W	4	1967	1977	22.4	3.68	17.3	2.28	10.2
ARGENTINE ISLANDS	65 15S	64 16W	11	1960	1970	34.9	3.71	31.3	4.41	3.7
ALMIRANTE BROWN	64 54S	62 52W	8	1958	1978	22.1	4.97	18.4	4.07	5.2

		BERMUDA	AZORES (HORTA)	CAPE VERDE ISLANDS (PORTO GRANDE)	TENERIFE	'NEWLYN'	NORTH SEA
	$\underline{S_a}$						
(a)	Amplitude (mm)	69	47	13	52	46	
	Phase (months)	8.7	7.8	8.3	8.1	10.2	
(b)	Amplitude (mm)	76	53	-	-	42	39
	Phase (months)	9.2	10.4			7.8	9.1
(c)	Amplitude (mm)	67	32	25	37	30	
	Phase (months)	9.0	8.4	8.6	8.3	8.5	
	$\underline{S_{sa}}$						
(d)	Amplitude (mm)	-	-	16	7	8	
	Phase (months)			4.6	2.2	4.4	
(e)	Amplitude (mm)	9	5			6	2
	Phase (months)	3.4	3.8	-	-	3.0	1.9

Table 4. Comparison of the 'residual' annual oscillation in MSL (a) from tide gauge and SLP measurements, (b) from measurements of steric height (Pattullo et al 1955), and (c) from steric height predictions of the model of Gill and Niiler (1973). Rows (d) and (e) are as for rows (a) and (b) but for the semiannual component.

	$\frac{f(SLP)}{f(MSL)}$	$\frac{S_A(SLP)}{S_{A(MSL)}}$	$\text{Phase}_{SLP} - \text{Phase}_{MSL}$	$R = \frac{f(SLP) \times v\ (SLP)}{f(MSL) \times v\ (MSL)}$
Reykjavik	.67	.70	1.15	.860
Murmansk	.40	.38	.89	.527
Tromso	.37	.34	.59	.591
Heimsjo	.28	.32	.19	.486
Bergen	.26	.22	.78	.524
Oslo	.20	.13	.34	.400
Esbjerg	.16	.10	1.36	.298
Stornoway	.37	.37	.54	.975
Malin Head	.40	.39	1.22	1.109
Lerwick	.42	.40	.93	.993
Aberdeen	.31	.30	.82	.787
Southend/Ostend	.21	.17	2.33	.688
Newlyn	.25	.23	1.63	.723
Brest	.31	.31	2.15	.639
Coruna	.24	.16	2.23	.468
Horta	.85	.71	3.94	.592

Table 5. Contribution of SLP to the average MSL seasonal cycle (col.1 - see text); the ratio of the amplitude of the annual SLP cycle to that of the annual MSL cycle (col.2); phase difference between the two annual cycles in months (col.3); the contribution of SLP to the 'variability' of the seasonal MSL cycle (col.4 - see text).

REGION	ANNUAL CYCLE		SEMI ANNUAL CYCLE	
	Amp. (miles per day)	Phase (months)	Amp. (miles per day)	Phase (months)
Florida	6.52	11.37	2.91	4.34
South of Hatteras	5.18	11.73	1.82	3.71
N.E. of Hatteras, South of Cape Cod	1.56	10.40	0.57	2.85

Table 6. Components of the seasonal cycle of the speed of the Florida Current in three regions along the US coast (from Fuglister 1951). The phase has been inverted to correspond to the maximum of MSL.

	ALL YEARS (1930-1980)				"POSITIVE ANOMALY YEARS" (1930-1980)				"NEGATIVE ANOMALY YEARS" (1930-1980)·			
	S_A		S_{SA}		S_A		S_{SA}		S_A		S_{SA}	
	Amp (mm)	Phase (months)	Amp (mm)	Phase (months)	Amp (mm)	Phase (months)	Amp (mm)	Phase (months)	Amp (mm)	Phase (months)	Amp (mm)	Phase (months)
Sitka	119.3	11.48	18.8	4.64	124.5	11.48	20.2	4.51	112.6	11.50	17.6	4.84
Prince Rupert	107.8	11.69	28.3	5.20	118.3	11.68	28.8	5.20	97.2	11.70	27.8	5.20
Neah Bay	133.4	0.16	19.5	0.15	147.9	0.16	15.1	0.57	120.2	0.16	25.5	5.93
Crescent City	76.0	11.35	31.7	0.91	84.5	11.56	38.5	1.11	68.0	11.06	26.7	0.57
San Francisco	38.9	10.02	26.3	1.12	43.7	10.79	31.3	1.23	41.4	9.18	21.7	0.94
San Diego	67.6	8.86	15.4	1.22	70.2	9.00	12.7	1.26	65.5	8.71	18.0	1.19

Table 7. Parameters of the seasonal cycle determined for 'all years' between 1930-1980 for selected stations on the American Pacific coast, and for 'positive' and 'negative anomaly years'.

	$S_{SA(MSL)}$ Observed		$S_{SA(SLP)}$ Estimated		Difference $S_{SA(MSL)}-S_{SA(SLP)}$	
	Amp. (mm)	Phase (months)	Amp. (mm)	Phase (months)	Amp. (mm)	Phase (months)
Norway						
Tromso	18.8	5.96	15.3	0.62	12.0	5.06
Harstad	15.2	5.55	9.6	0.66	14.4	4.92
Narvik	21.0	5.53			19.5	5.08
Kabelvag	14.5	4.89			19.5	4.42
Trondheim	26.1	5.14	8.3	5.87	20.9	4.87
Heimsjo	11.0	5.05			8.4	4.24
Kristiansund N.	15.0	4.93	8.5	5.88	12.6	4.36
Alesund	14.1	4.91			12.0	4.30
Kjolsdal	5.9	4.77			8.2	3.57
Maloy	15.9	4.46			17.4	3.97
Bergen	16.8	5.11	8.7	5.89	12.6	4.61
Other N. Hemi.						
Russkaya Gavan	22.9	5.88	6.6	0.24	16.9	5.74
Murmansk	15.5	5.90	6.4	0.29	10.0	5.65
Lerwick	14.3	5.81	5.8	0.21	9.3	5.57
Reykjavik	11.1	0.25	4.4	1.03	8.7	5.89
Barentsburg	21.0	0.39	9.9	4.66	25.3	0.76
Antarctica						
Bahia Esperanza	17.3	2.28	23.6	3.00	-	-
Argentine Is.	31.3	4.41	25.2	3.08		
Almirante Brown	18.4	4.07	20.9	2.88		

Table 8. Parameters of the semiannual cycle in MSL (from Tables 1-3) for stations at higher latitudes than 60deg N or S together with the estimated contribution from SLP alone and the difference between the two.

9. Figure Captions

(1) Amplitude and phase of the annual (a,b) and semiannual (c,d) MSL cycles for stations in Europe versus degrees North.

(2) Contribution from SLP to the MSL annual (a,b) and semiannual (c,d) cycles in Europe versus degrees North.

(3) Average monthly values of MSL for selected European stations.

(4) MSL annual and semiannual amplitudes ((a) and (c) respectively) and phases ((b) and (d)) for Baltic stations in Group 1.

(5) Amplitudes (in mm) of the annual cycle of MSL in the area of the North Sea. (Not all stations from Tables 1-3 for Holland and southern England are shown).

(6) (a) Yearly relative strength ('V') of the MSL seasonal cycle at Aberdeen; (b) Yearly relative strength ('V') for the SLP contribution to MSL at Aberdeen.

(7) Amplitude and phase of the annual (a,b) and semiannual (c,d) MSL cycles for stations in the Gulf of Mexico versus degrees West.

(8) Ampitude and phase of the annual (a,b) and semiannual (c,d) MSL cycles for stations on the American Atlantic coast versus degrees North.

(9) Average monthly values of MSL for selected stations in the Gulf of Mexico and the American Atlantic coast.

(10) Contribution from SLP to the MSL annual (a,b) and semiannual (c,d) cycles in the Gulf of Mexico versus degrees West.

(11) Contribution from SLP to the MSL annual (a,b) and semiannual (c,d) cycles on the American Atlantic coast versus degrees North.

(12) Amplitude and phase of the annual (a,b) and semiannual (c,d) MSL cycles for stations on the American Pacific coast versus degrees North.

(13) Contribution from SLP to the MSL annual (a,b) and semiannual (c,d) cycles on the American Pacific coast versus degrees North.

(14) Average monthly values of MSL for selected stations on the American Pacific coast.

(15) Amplitude and phase of the annual (a,b) and semiannual (c,d) MSL cycles for stations in Asia versus degrees North: Japan stations are denoted by (x), mainland Asia (+), Philippines (*).

(16) Contribution from SLP to the MSL annual (a,b) and semiannual (c,d) cycles for stations in Asia versus degrees North.

(17) Worldwide summary of the phase of the annual cycle of Mean Sea Level. Tide gauge positions are shown by black dots. Areas marked 'A', 'B', 'C' and 'D' have annual cycles peaking between months 0.0-3.0, 3.0-6.0, 6.0-9.0 and 9.0-12.0 respectively.

(18) Worldwide summary of the phase of the semiannual cycle of Mean Sea Level. Areas marked 'A' have the semiannual MSL cycle peaking

between months 1.5 and 4.5, while areas marked 'B' peak between months 4.5 and 1.5.

(19) Worldwide summary of the amplitude (in mm) of the annual cycle of Mean Sea Level.

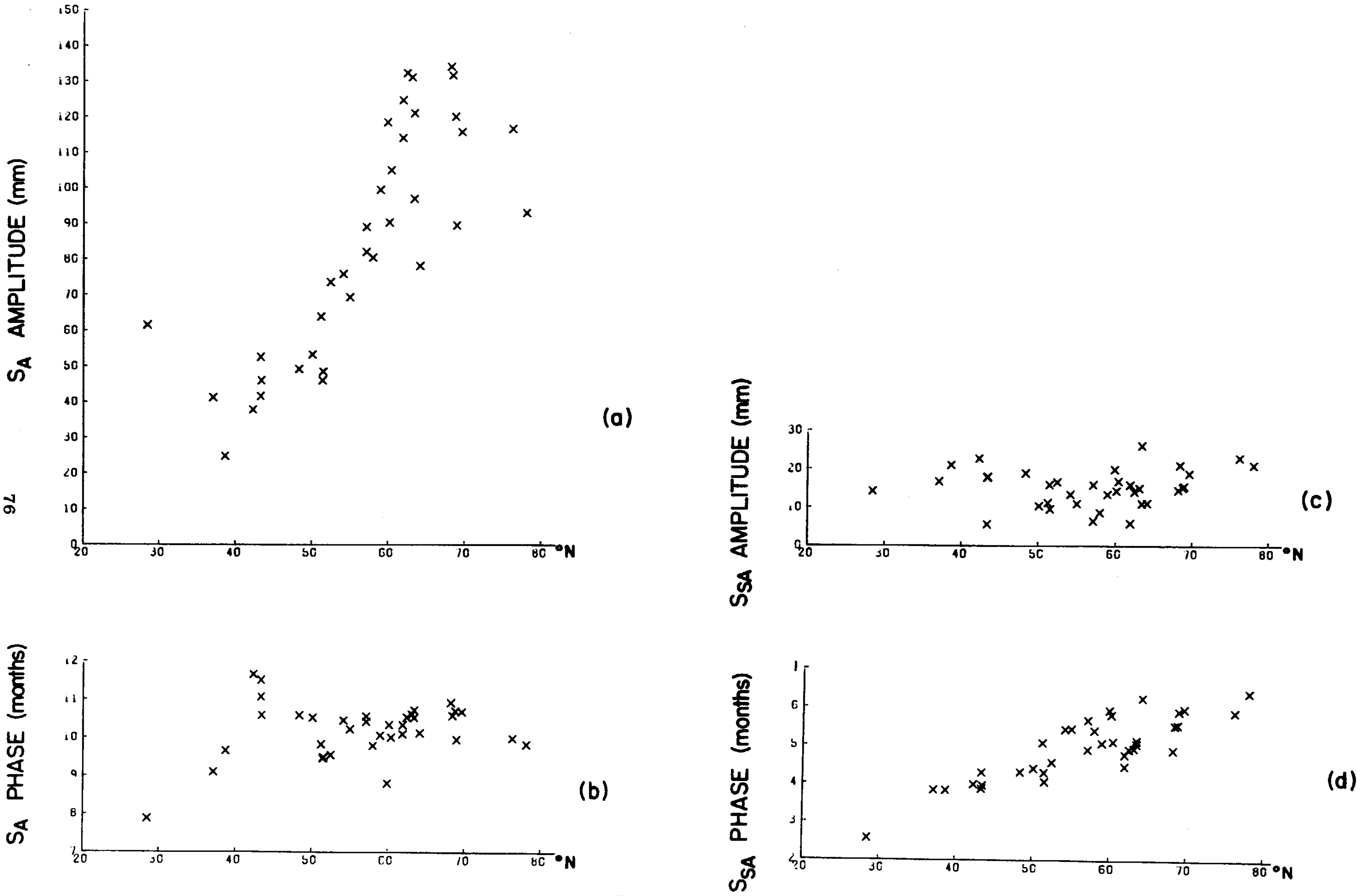
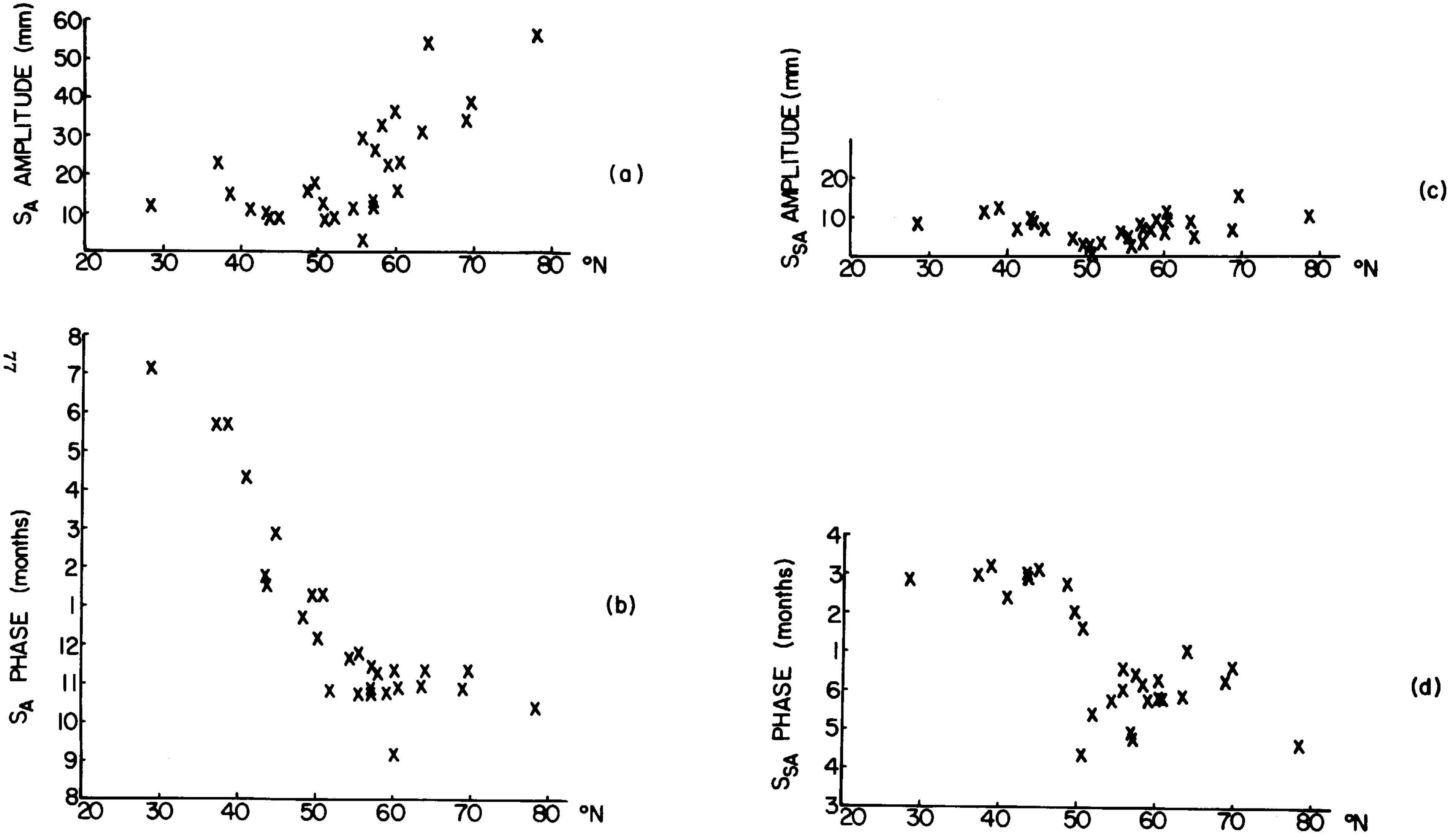

S_A AMPLITUDE (mm)
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
20
30
40
50
60
70
80
°N
(a)
S_{SA} AMPLITUDE (mm)
30
20
10
0
(c)
S_A PHASE (months)
12
11
10
9
8
7
(b)
S_{SA} PHASE (months)
1
6
5
4
3
2
(d)

Figure 1



S_A AMPLITUDE (mm)
60
50
40
30
20
10
20
30
40
50
60
70
80
°N
(a)
S_{SA} AMPLITUDE (mm)
20
10
(c)
S_A PHASE (months)
8
7
6
5
4
3
2
1
12
11
10
9
(b)
S_{SA} PHASE (months)
(d)

Figure 2

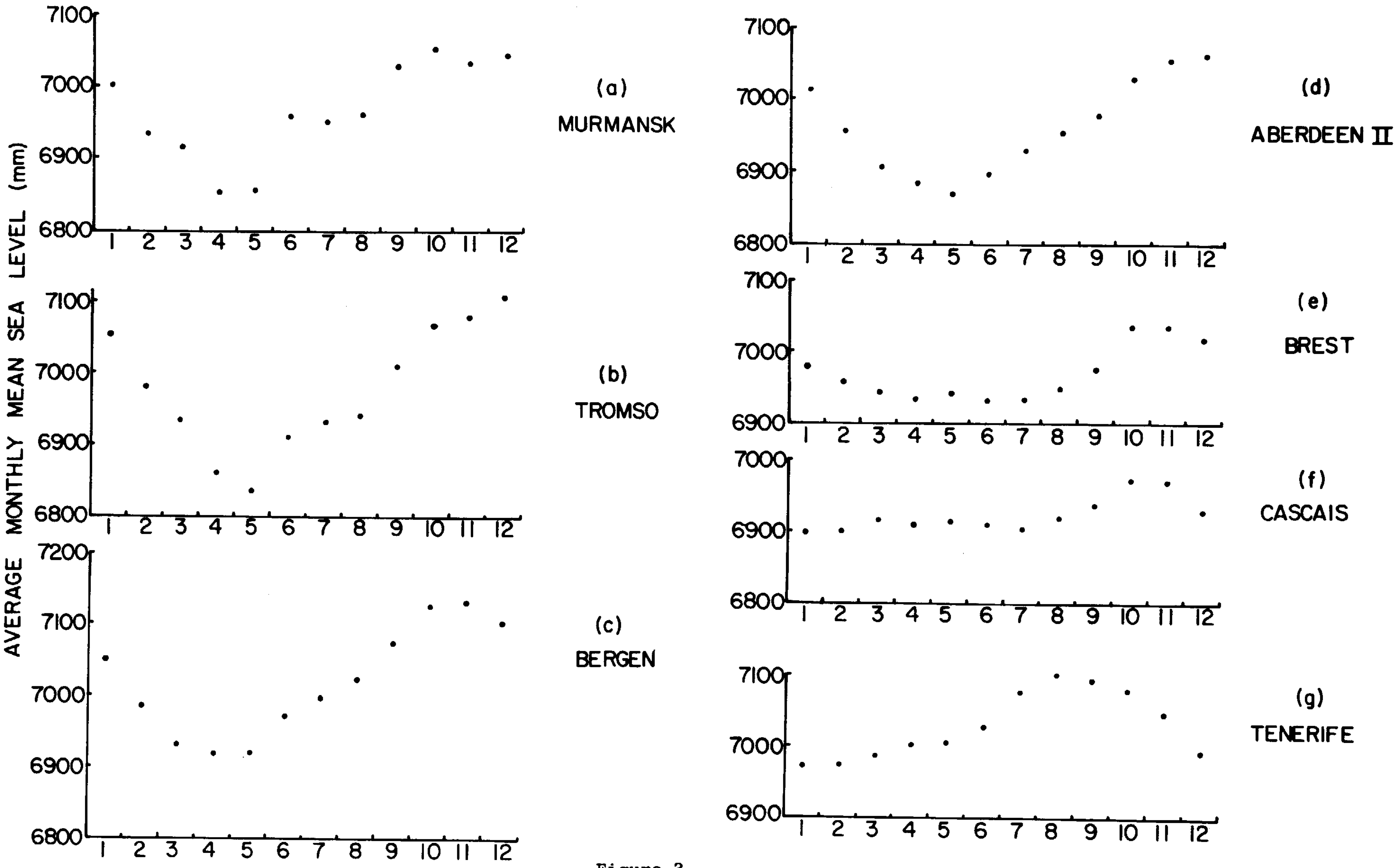

AVERAGE MONTHLY MEAN SEA LEVEL (mm)
(a) MURMANSK
(b) TROMSO
(c) BERGEN
(d) ABERDEEN II
(e) BREST
(f) CASCAIS
(g) TENERIFE
6800
6900
7000
7100
7200
1 2 3 4 5 6 7 8 9 10 11 12

Figure 3

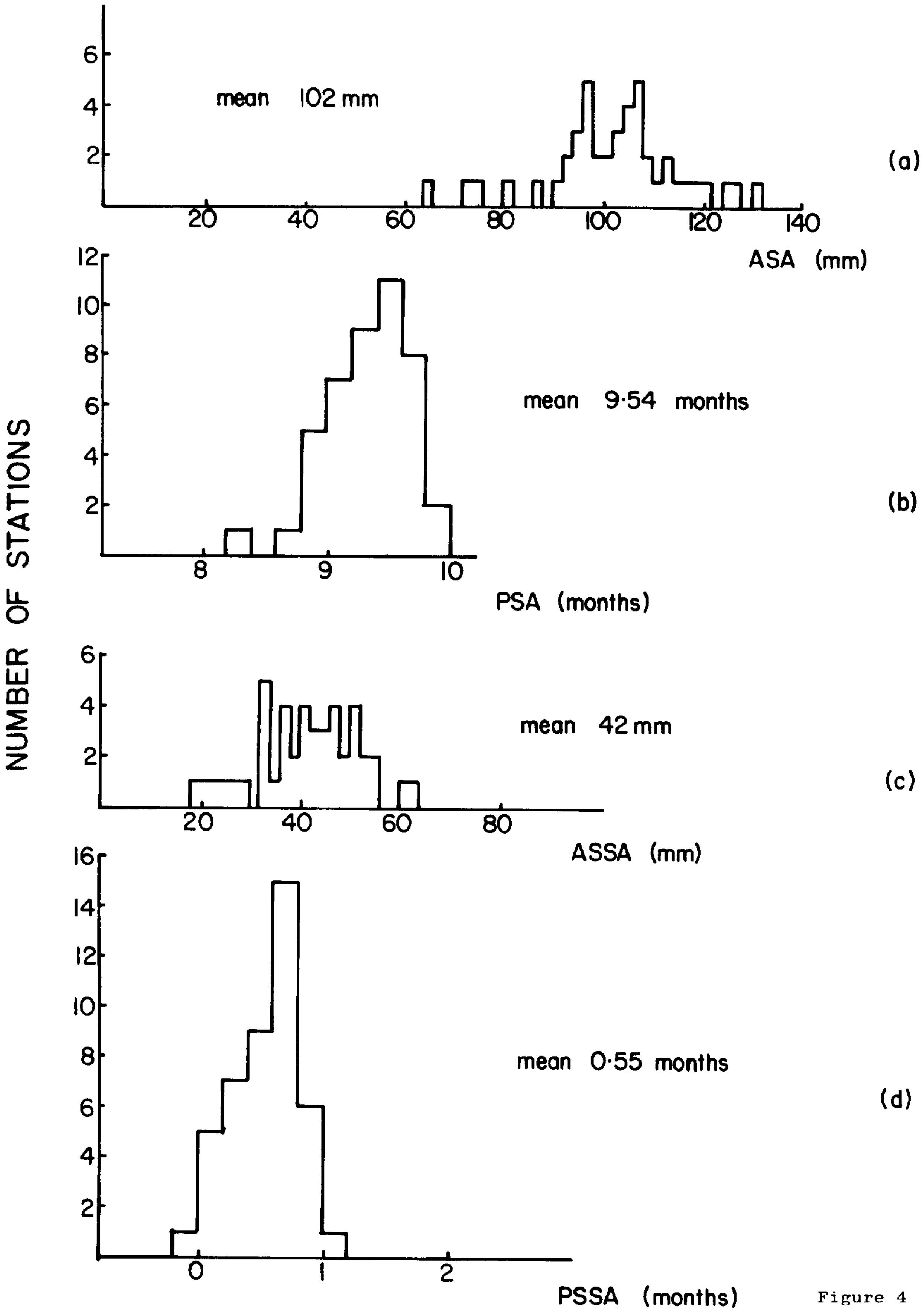

NUMBER OF STATIONS
6
4
2
mean 102 mm
20
40
60
80
100
120
140
ASA (mm)
(a)
12
10
8
6
4
2
mean 9·54 months
8
9
10
PSA (months)
(b)
6
4
2
mean 42 mm
20
40
60
80
ASSA (mm)
(c)
16
14
12
10
8
6
4
2
mean 0·55 months
0
1
2
PSSA (months)
(d)

Figure 4

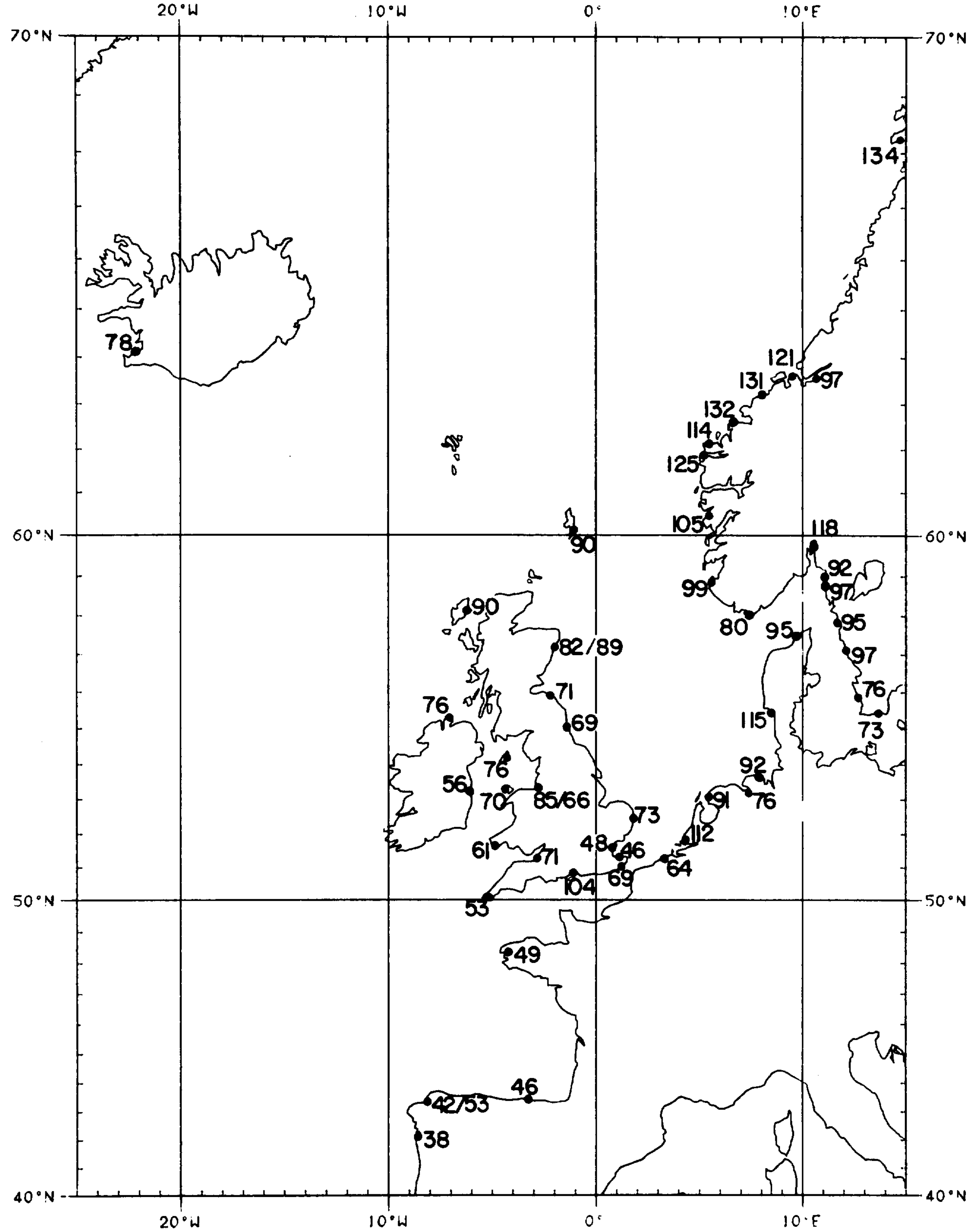

20°W
10°W
0°
10°E
70°N
60°N
50°N
40°N
134
78
121
131
97
132
114
125
105
118
90
92
97
99
80
95
95
190
82/89
97
71
76
76
69
115
73
92
76
56
70
85/66
91
76
73
112
48
46
61
71
64
104
69
53
49
46
42/53
38

Figure 5

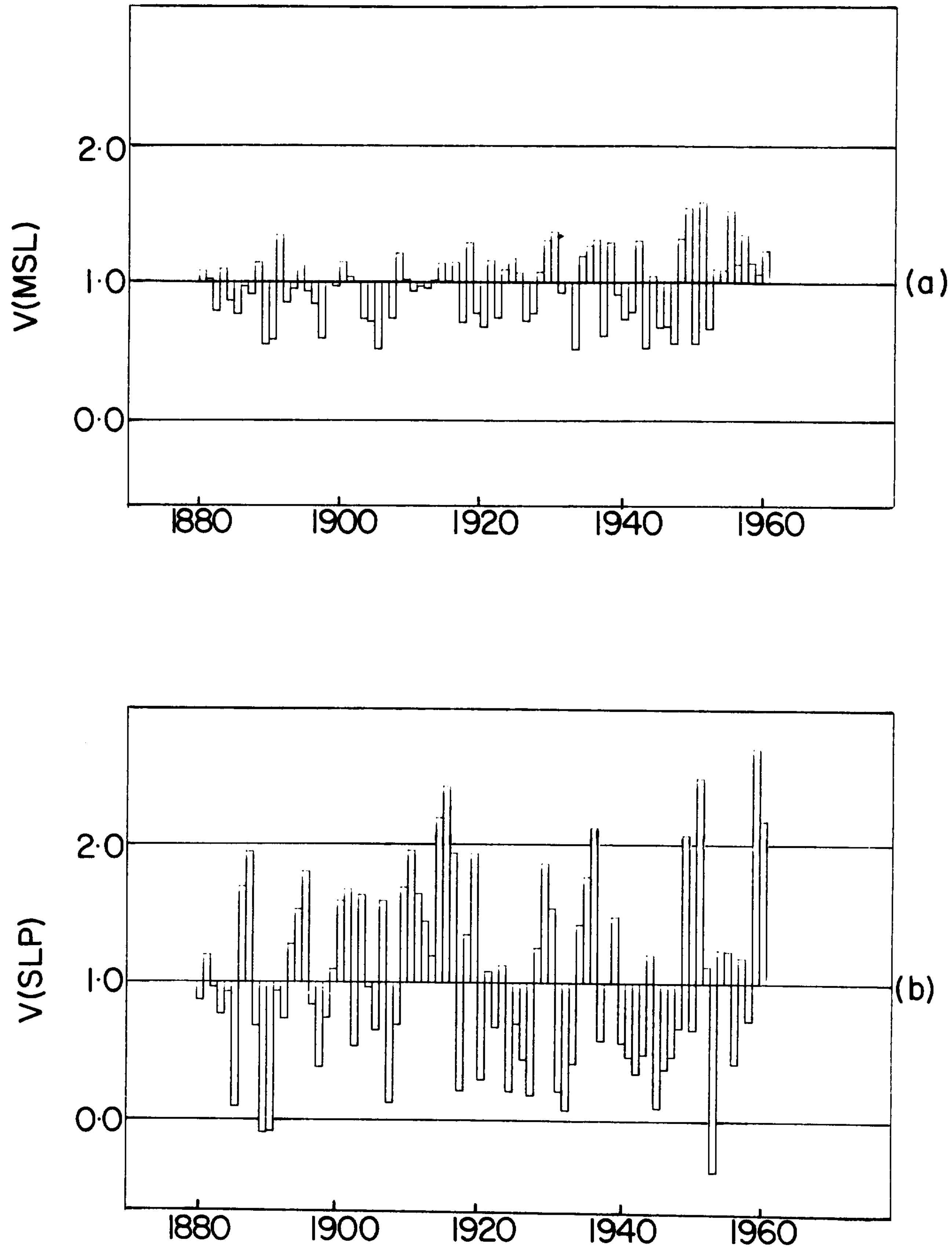

V(MSL)
2·0
1·0
0·0
1880
1900
1920
1940
1960
(a)
V(SLP)
2·0
1·0
0·0
1880
1900
1920
1940
1960
(b)

Figure 6

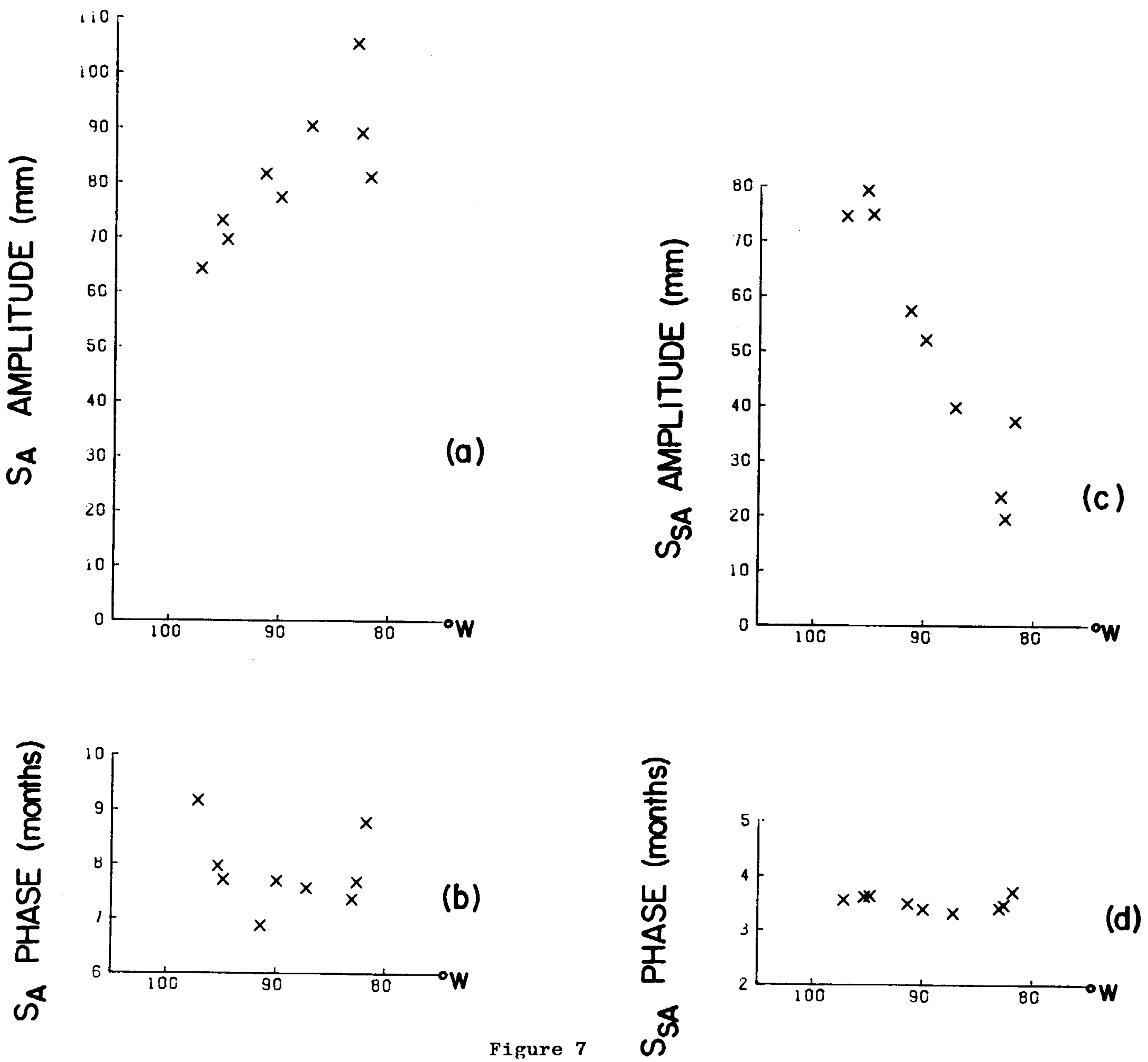

S_A AMPLITUDE (mm)
110
100
90
80
70
60
50
40
30
20
10
0
100
90
80
°W
(a)
S_SA AMPLITUDE (mm)
80
70
60
50
40
30
20
10
0
(c)
S_A PHASE (months)
10
9
8
7
6
(b)
S_SA PHASE (months)
5
4
3
2
(d)

Figure 7

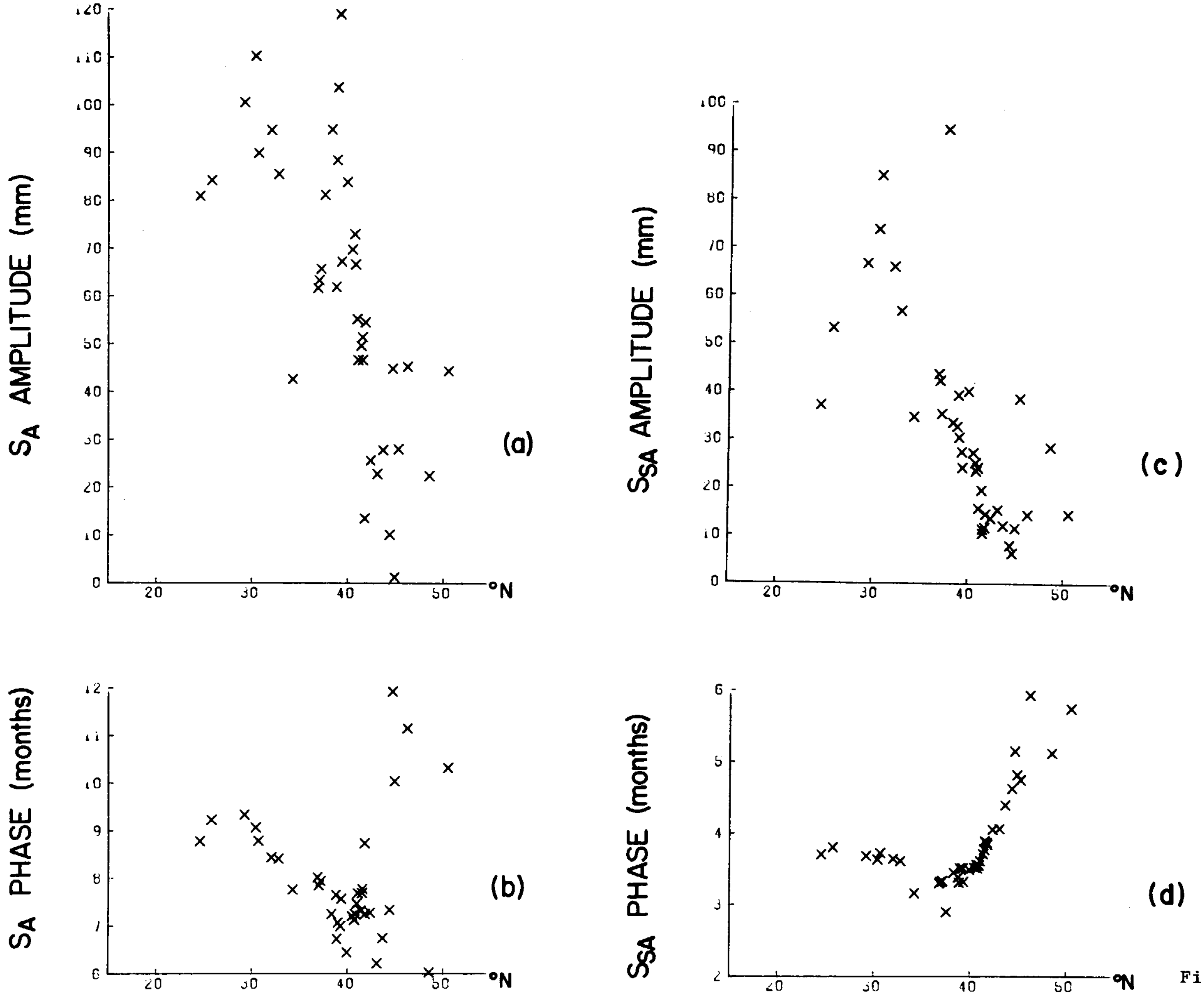

S_A AMPLITUDE (mm)
120
110
100
90
80
70
60
50
40
30
20
10
0
20
30
40
50
°N
(a)
S_SA AMPLITUDE (mm)
100
90
80
70
60
50
40
30
20
10
0
20
30
40
50
°N
(c)
S_A PHASE (months)
12
11
10
9
8
7
6
20
30
40
50
°N
(b)
S_SA PHASE (months)
6
5
4
3
2
20
30
40
50
°N
(d)

Figure 8

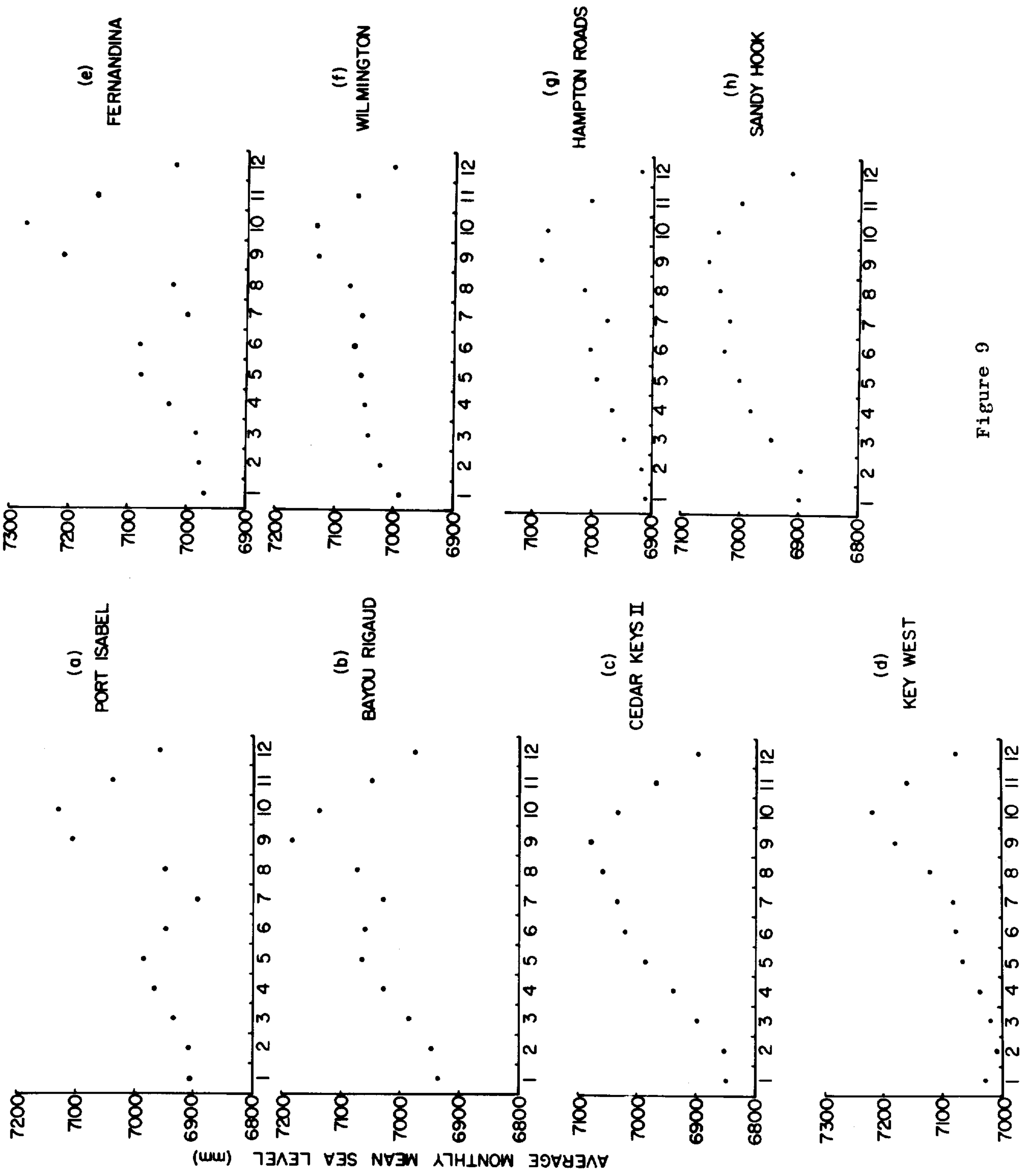

(a) PORT ISABEL
(b) BAYOU RIGAUD
(c) CEDAR KEYS II
(d) KEY WEST
(e) FERNANDINA
(f) WILMINGTON
(g) HAMPTON ROADS
(h) SANDY HOOK
AVERAGE MONTHLY MEAN SEA LEVEL (mm)
7300
7200
7100
7000
6900
6800
1 2 3 4 5 6 7 8 9 10 11 12

Figure 9

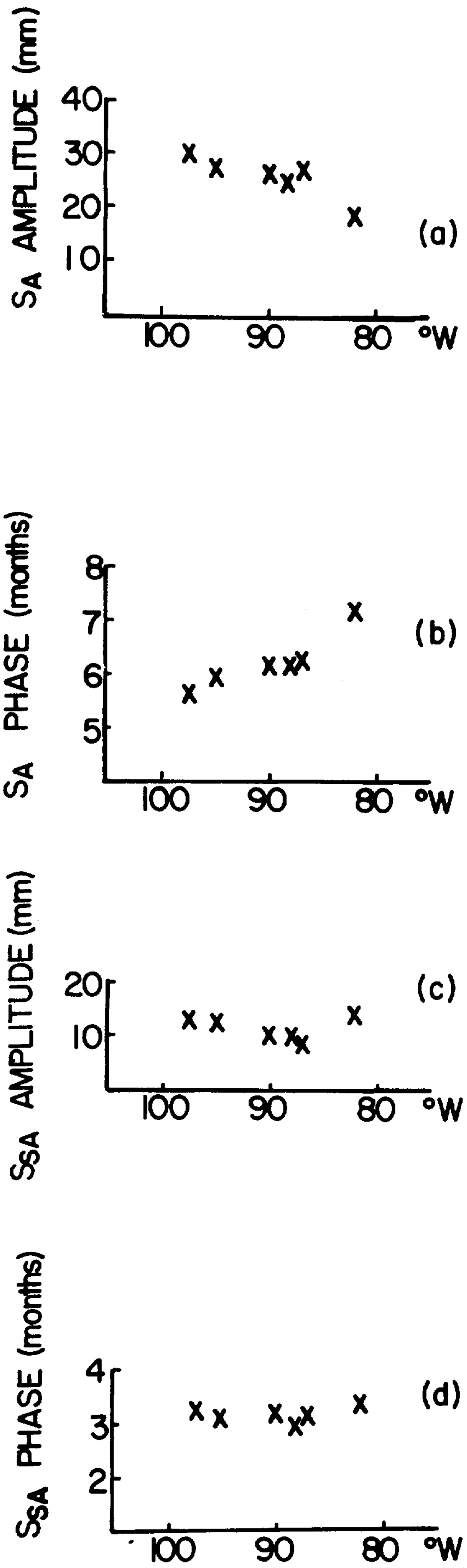


Figure 10

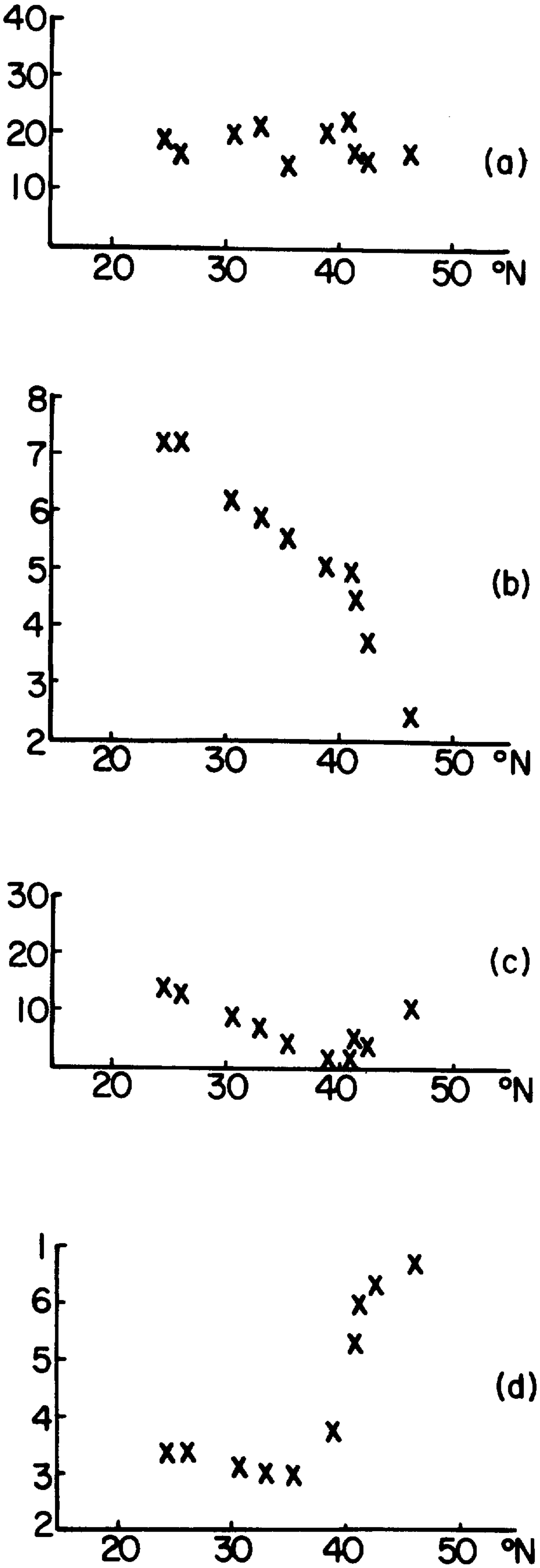


Figure 11

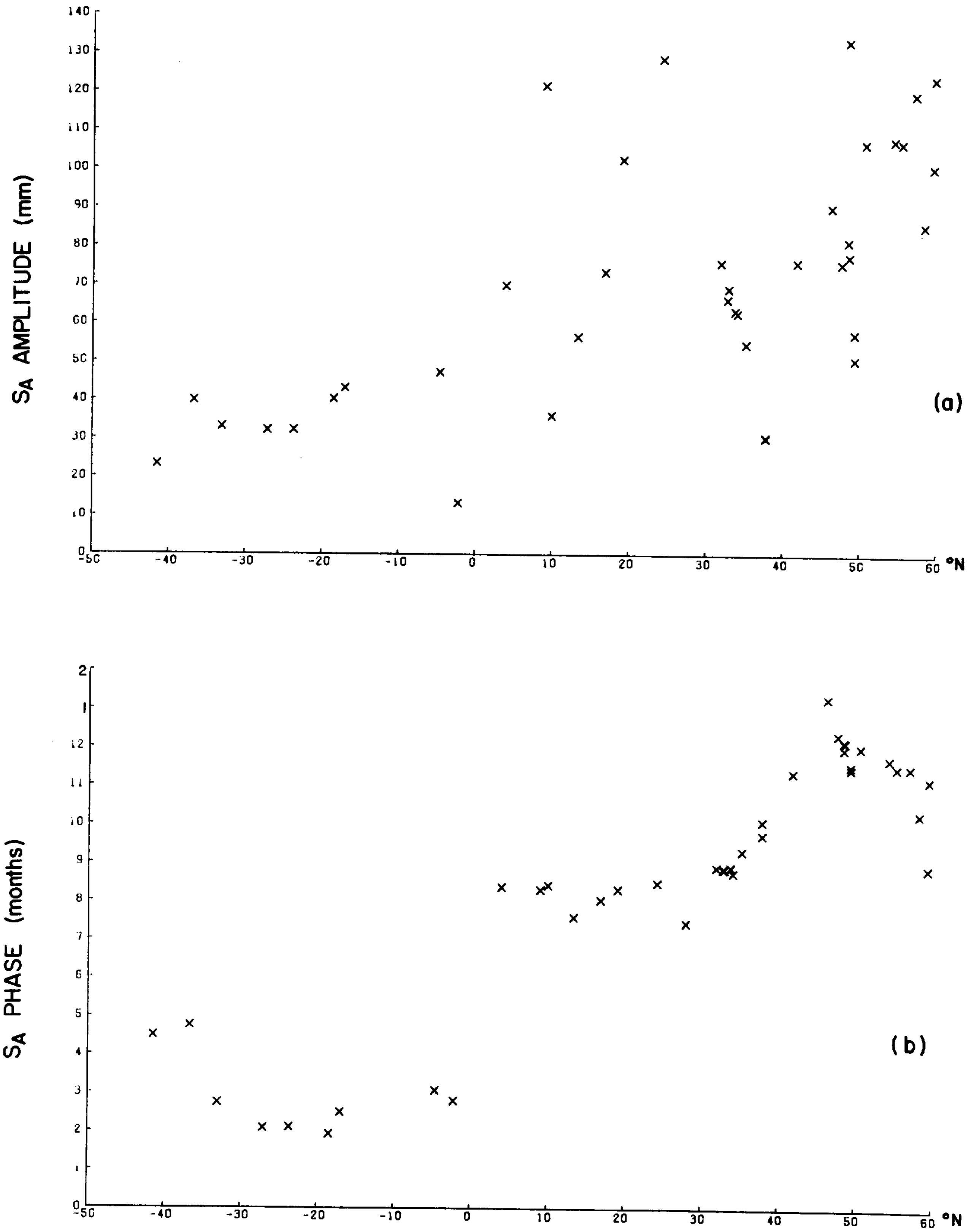

SA AMPLITUDE (mm)
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-50
-40
-30
-20
-10
0
10
20
30
40
50
60
°N
(a)
SA PHASE (months)
2
1
12
11
10
9
8
7
6
5
4
3
2
1
0
-50
-40
-30
-20
-10
0
10
20
30
40
50
60
°N
(b)

Figure 12

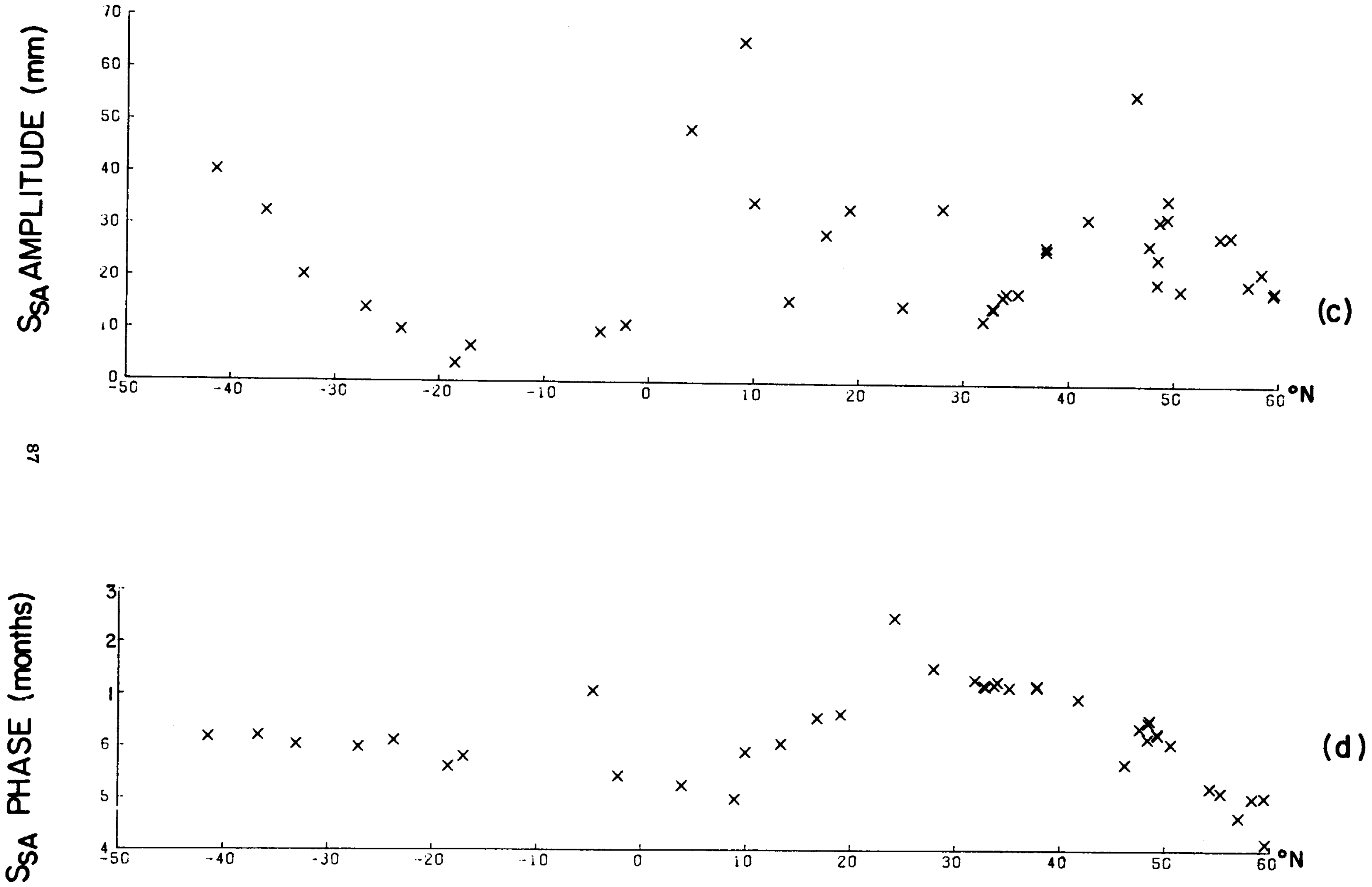

S_{SA} AMPLITUDE (mm)
70
60
50
40
30
20
10
0
-50
-40
-30
-20
-10
0
10
20
30
40
50
60
°N
(c)
S_{SA} PHASE (months)
3
2
1
6
5
4
-50
-40
-30
-20
-10
0
10
20
30
40
50
60
°N
(d)

Figure 12

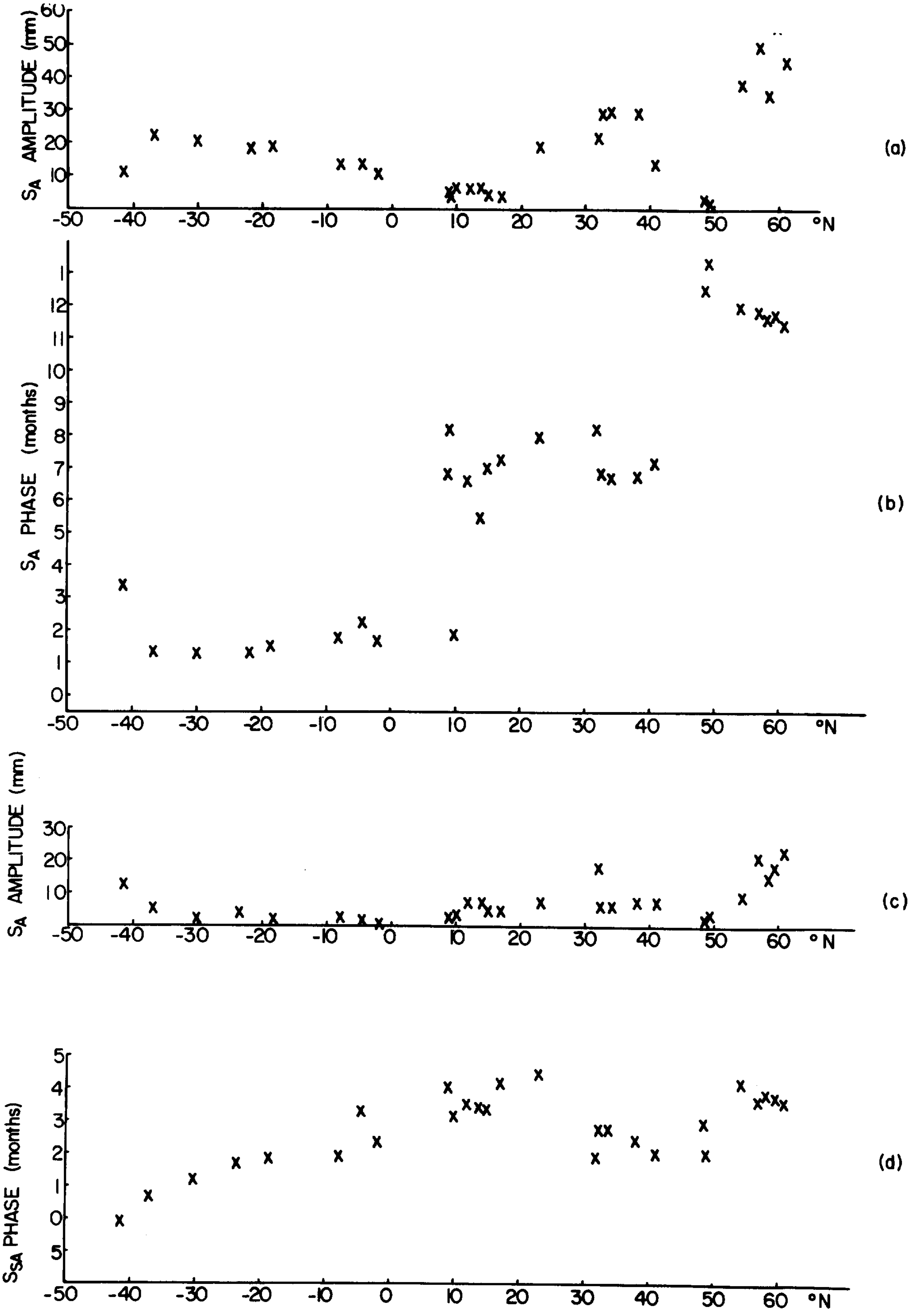

S_A AMPLITUDE (mm)
60
50
40
30
20
10
-50
-40
-30
-20
-10
0
10
20
30
40
50
60
°N
(a)
S_A PHASE (months)
1
12
11
10
9
8
7
6
5
4
3
2
1
0
(b)
S_A AMPLITUDE (mm)
30
20
10
(c)
S_SA PHASE (months)
5
4
3
2
1
0
5
(d)

Figure 13

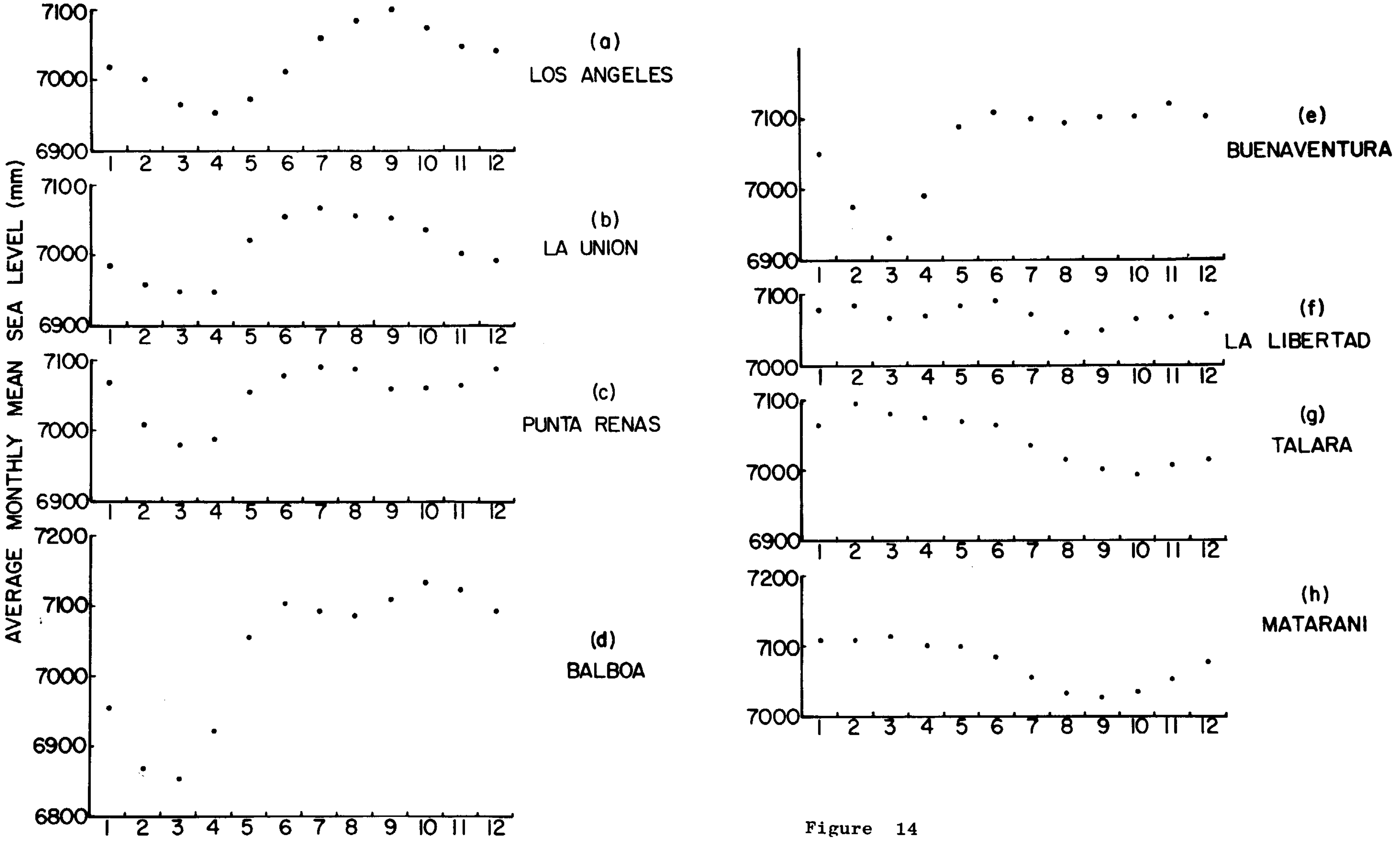

AVERAGE MONTHLY MEAN SEA LEVEL (mm)
(a)
LOS ANGELES
(b)
LA UNION
(c)
PUNTA RENAS
(d)
BALBOA
(e)
BUENAVENTURA
(f)
LA LIBERTAD
(g)
TALARA
(h)
MATARANI
6800
6900
7000
7100
7200
1 2 3 4 5 6 7 8 9 10 11 12

Figure 14

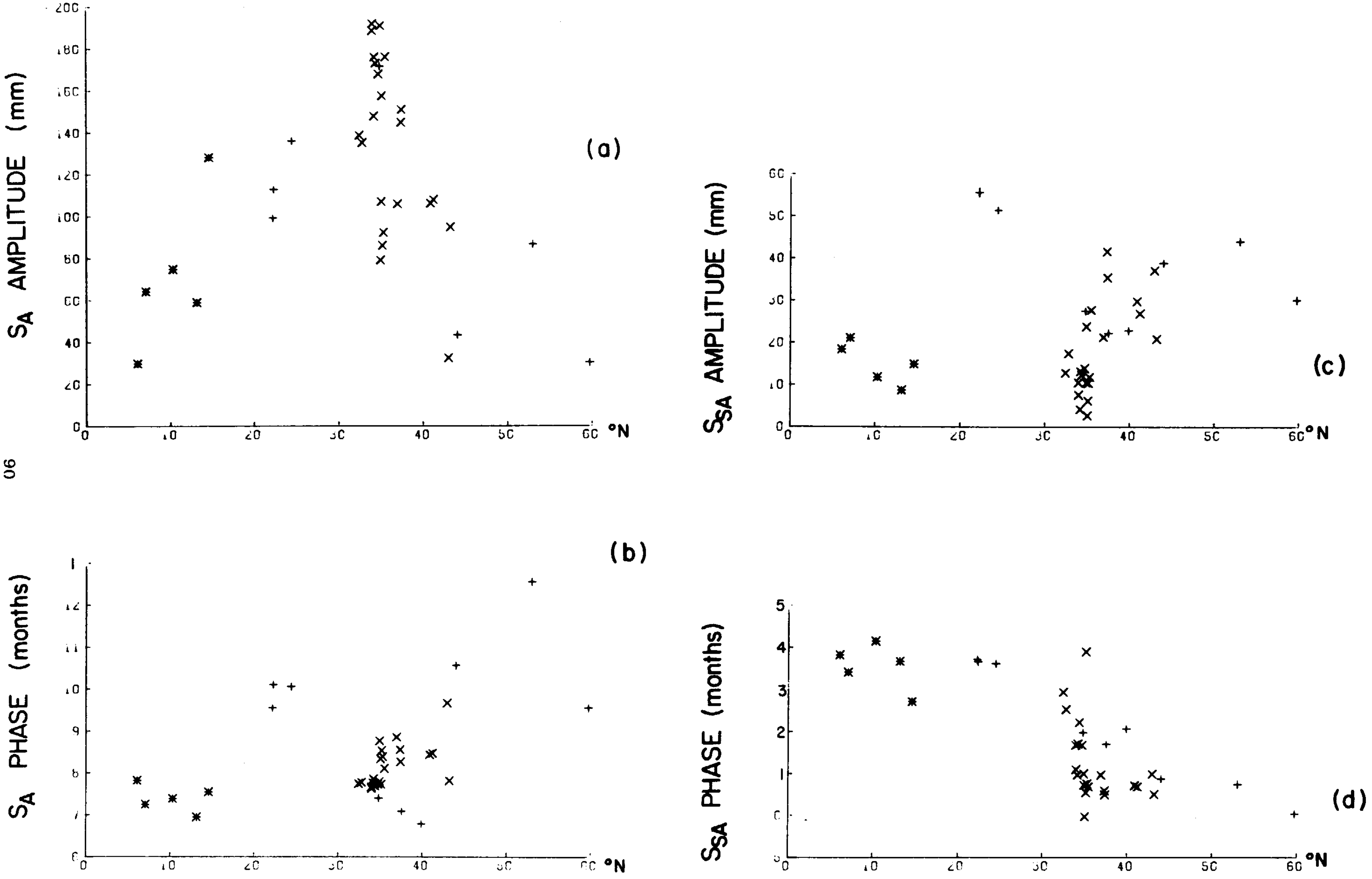
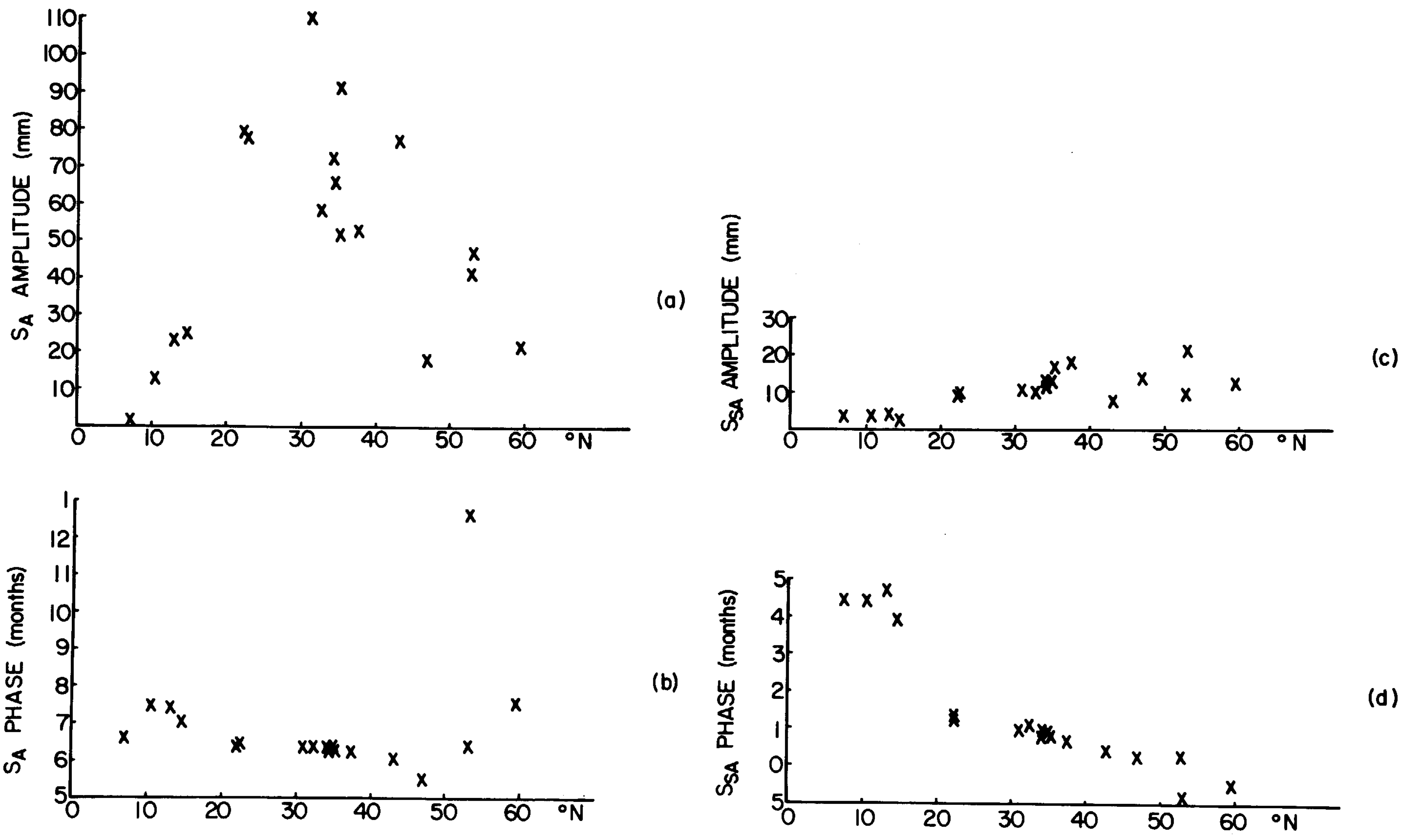

(a)
S_A AMPLITUDE (mm)
0
20
40
60
80
100
120
140
160
180
200
(b)
S_A PHASE (months)
6
7
8
9
10
11
12
1
(c)
S_{SA} AMPLITUDE (mm)
0
10
20
30
40
50
60
(d)
S_{SA} PHASE (months)
0
1
2
3
4
5
0
10
20
30
40
50
60
°N

Figure 15



(a)
S$_A$ AMPLITUDE (mm)
110
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
°N
(b)
S$_A$ PHASE (months)
1
12
11
10
9
8
7
6
5
0
10
20
30
40
50
60
°N
(c)
S$_{SA}$ AMPLITUDE (mm)
30
20
10
0
10
20
30
40
50
60
°N
(d)
S$_{SA}$ PHASE (months)
5
4
3
2
1
0
5
0
10
20
30
40
50
60
°N

Figure 16

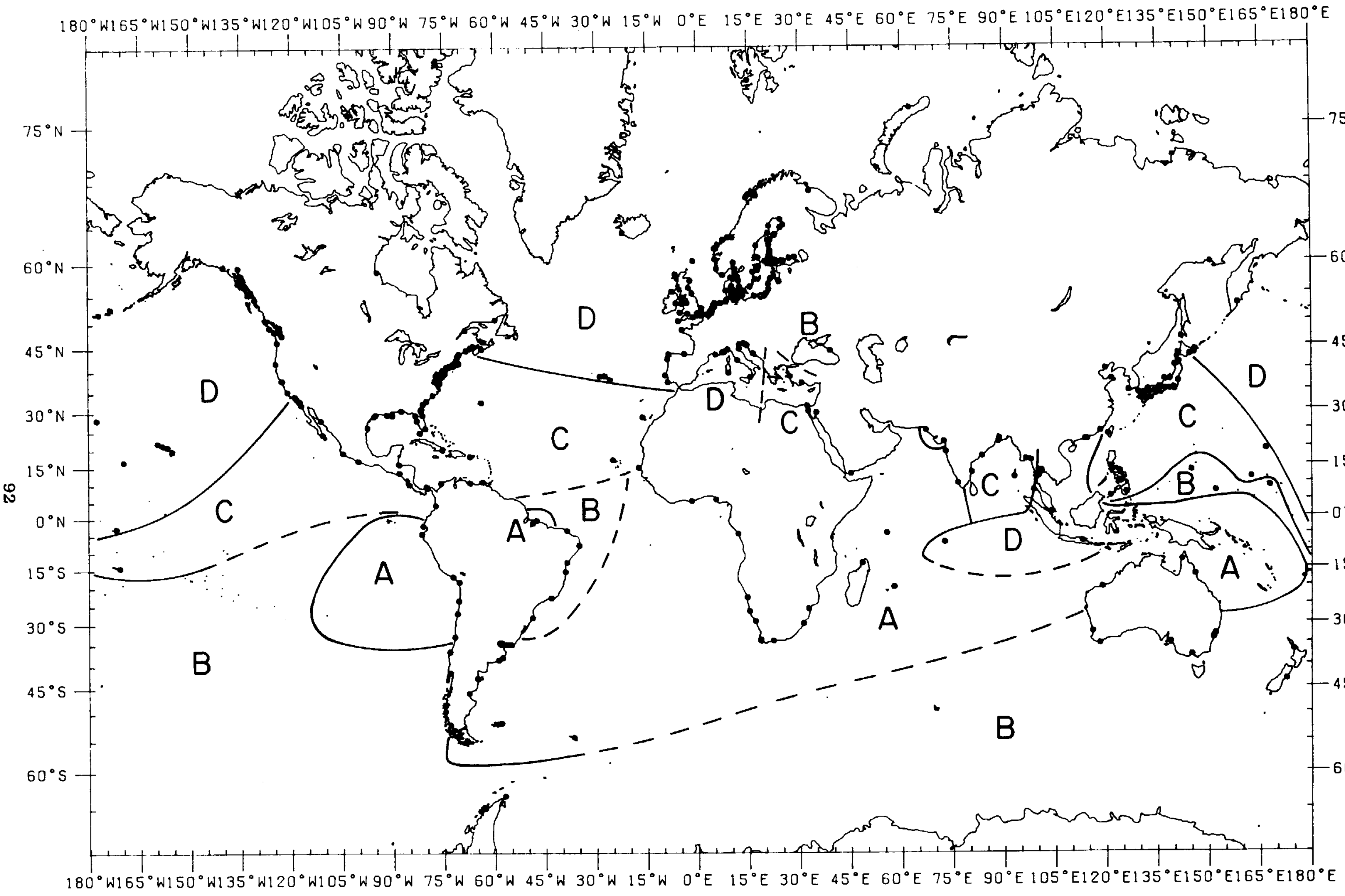

180°W 165°W 150°W 135°W 120°W 105°W 90°W 75°W 60°W 45°W 30°W 15°W 0°E 15°E 30°E 45°E 60°E 75°E 90°E 105°E 120°E 135°E 150°E 165°E 180°E
75°N
60°N
45°N
30°N
15°N
0°N
15°S
30°S
45°S
60°S
D
C
B
A
A
B
C
D
D
B
C
A
D
C
B
C
D
A
B

Figure 17

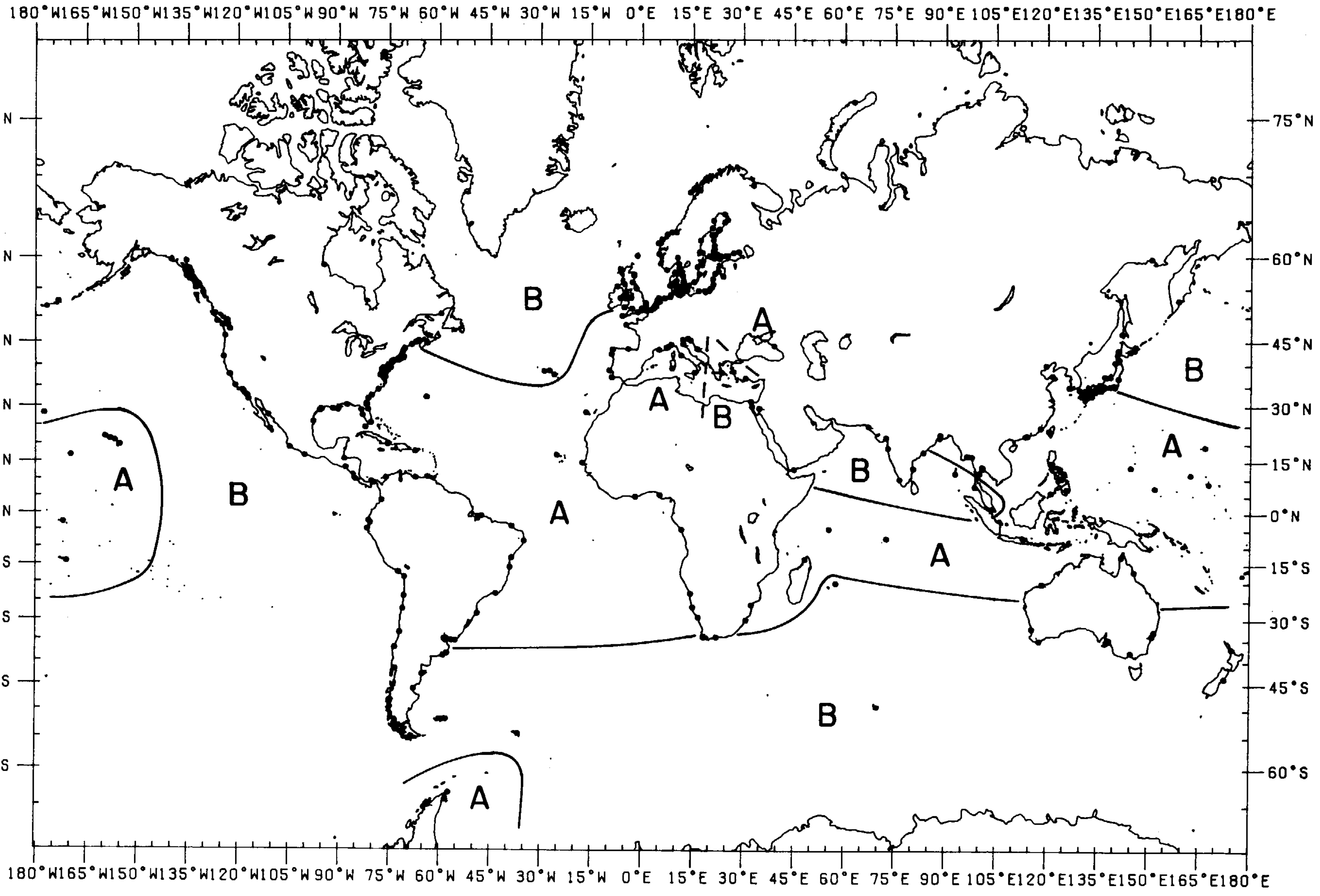

180°W 165°W 150°W 135°W 120°W 105°W 90°W 75°W 60°W 45°W 30°W 15°W 0°E 15°E 30°E 45°E 60°E 75°E 90°E 105°E 120°E 135°E 150°E 165°E 180°E
75°N
60°N
45°N
30°N
15°N
0°N
15°S
30°S
45°S
60°S
B
A
B
A
B
A
B
A
A
B
B
A
A
B
A

Figure 18

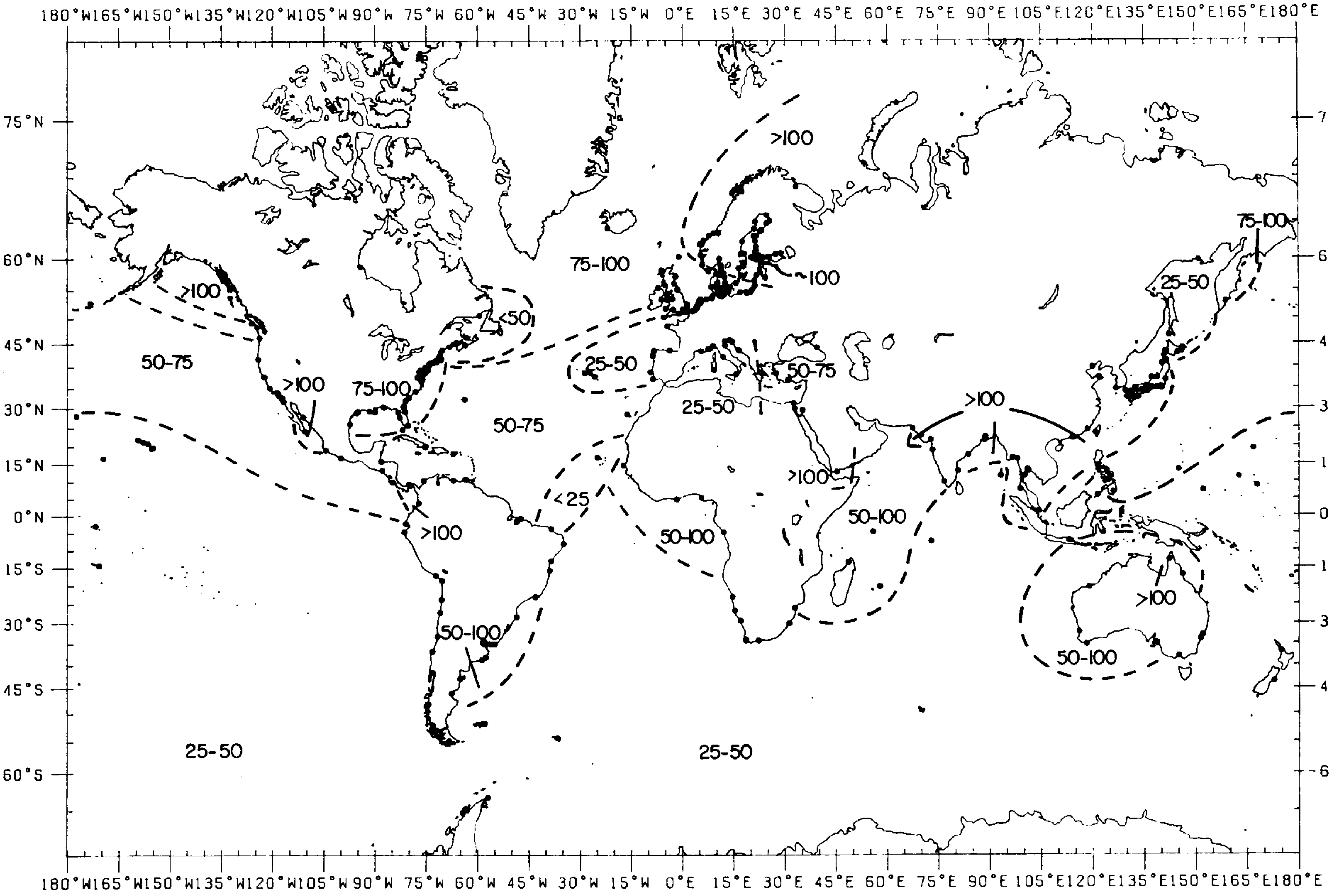

180°W 165°W 150°W 135°W 120°W 105°W 90°W 75°W 60°W 45°W 30°W 15°W 0°E 15°E 30°E 45°E 60°E 75°E 90°E 105°E 120°E 135°E 150°E 165°E 180°E
75°N
60°N
45°N
30°N
15°N
0°N
15°S
30°S
45°S
60°S
>100
75-100
~100
75-100
25-50
>100
<50
25-50
50-75
50-75
>100
75-100
25-50
>100
50-75
<25
>100
>100
50-100
50-100
>100
50-100
50-100
25-50
25-50

Figure 19